Chapter – 3

Spatio-temporal Pattern of Geochemical Properties of Groundwater

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3.1 Geochemical Properties of Groundwater:

Geochemical properties of groundwater play a significant role in determining its uses for different purposes. On one hand, these parameters are individually significant and minor deviation from the norm can create issues related to the quality of water, on the other hand, these parameters are dependent to each other (**Demirel** & **Güler** 2006). Hence, to understand the groundwater processes, it is essential to look into the groundwater parameters individually as well as in association with each other. In the present study, ten groundwater parameters (*arsenic* (As), *pH*, *total dissolved solids* (TDS), *electrical conductivity* (EC), *iron* (Fe), *chloride* (Cl^-), *sulfate* (SO_4^{-2}), *total hardness as $CaCO_3$*, *nitrite* (NO_2) and *depth*) were taken into consideration. Parameters such as *arsenic* (As) and *nitrite* (NO_2) disturb the water quality of water even if they are present in a trace amount (**Ghosh** and **Kanchan** 2014). *pH* is the power of hydrogen which determines the level of acidity or alkalinity. A significant variation in the level of *pH* can alter the characteristics of the ground water. *Total dissolved solids* (TDS) and *electrical conductivity* (EC) indicates the amount of dissolved solids into the water which determines its usability. Similarly, major ions like *sulfate* (SO_4^{-2}) and *chloride* (Cl^-) also determine the portability. Individually, *Iron* (Fe), does not create any issue regarding the quality of water but excess amount can change its colour and taste (**Haman** & **Bottcher** 1986). In the present work, these parameters were chemically examined, and their results were analysed by using appropriate statistical tools. The groundwater sampling locations are illustrated in Fig. 3.1.

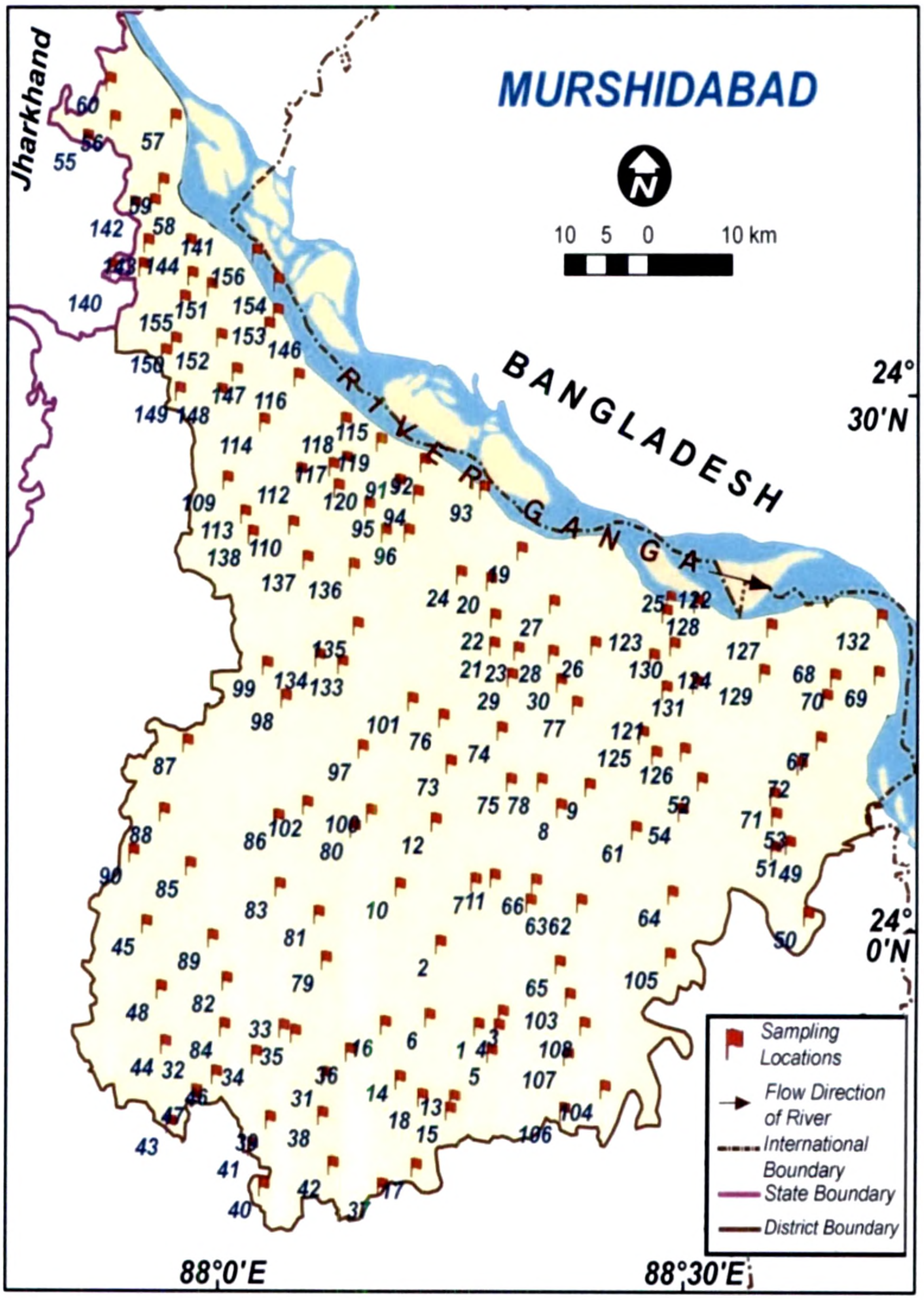


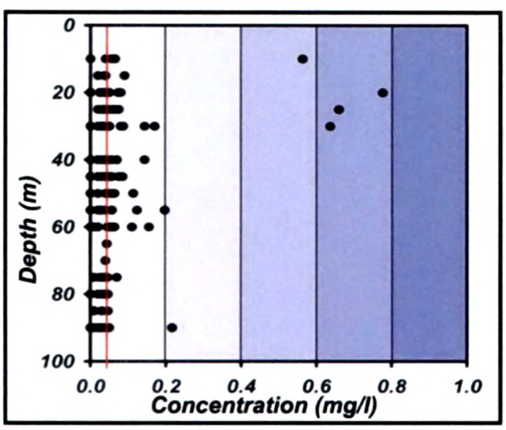
Fig. 3.1: Groundwater Sampling Locations

3.2 General Characteristics of Groundwater:

3.2.1. Pre-monsoon:

During the pre-monsoon season the concentration of *arsenic* ranged between BDL to 0.78 mg/l with an average of 0.06 mg/l (Fig. 3.2) (Table 3.1). A considerably high variation in the level of concentration of *arsenic* in ground water was observed (0.10 mg/l) in the district. Skewness and kurtosis also depicted positive and high values of +5.27 and +29.63 respectively. The value of kurtosis showed high peakedness, justifying the high standard deviation. The maximum concentration of arsenic was observed in the depths of 0-25 mbgl and 50-90 mbgl (Fig. 3.3).

Pre-monsoon Season (Arsenic)



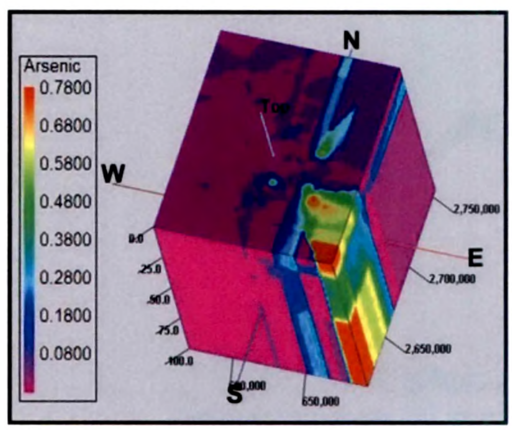


Fig. 3.2 Concentration **Fig. 3.3 Distribution**

The level of *pH* varied between 6.27 and 8.07, ranging between slightly acidic to the alkaline condition (Fig.3.4). The mean of *pH* in groundwater was 7.38 indicating a normal condition and a less deviation of 0.39. Skewness and kurtosis showed low values. Negative value of skewness (-0.57) was observed while kurtosis showed positive value (+0.01). The former is the indication of slightly less availability of higher values while latter indicates flatter distribution of data. The *pH* value between 7 and 7.40 was found extensively from 10 mbgl to 90 mbgl (Fig. 3.5). The concentration of *TDS* varied between a 267.97 mg/l to 1250.57 mg/l (Fig. 3.6).

Pre-monsoon Season (pH)

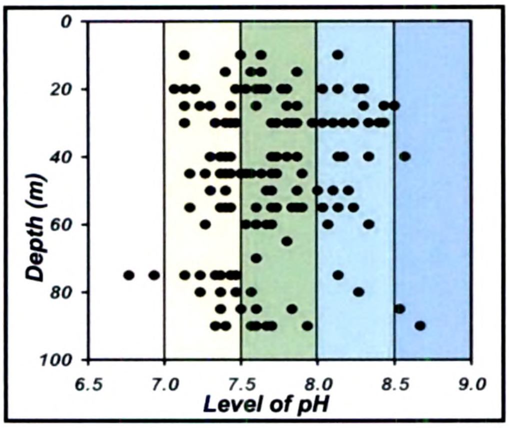


Fig. 3.4 Level of pH

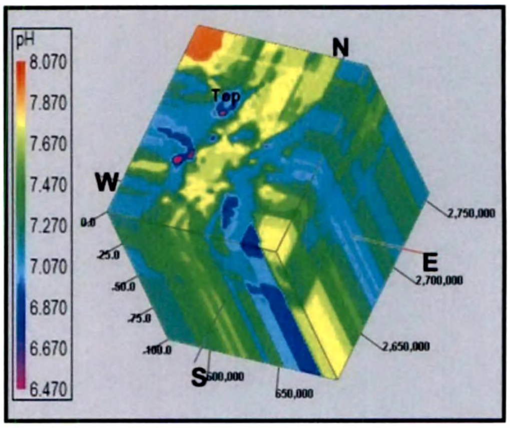


Fig. 3.5 Distribution

Table: 3.1 Descriptive statistics of Groundwater Parameters during Pre-monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.78	0.06	0.10	5.27	29.63
pH	156	6.27	8.07	7.38	0.39	-0.57	0.01
TDS	156	267.97	1250.57	599.52	154.72	0.66	1.59
EC	156	0.53	2.50	1.19	0.31	0.68	1.69
Iron	156	0.70	82.32	7.78	10.79	3.64	16.70
Chloride	156	15.23	434.13	82.78	50.58	2.29	13.49
Sulfate	156	45.87	1458.87	395.72	339.58	0.89	-0.32
Total Hardness as $CaCO_3$	156	48.03	1242.33	449.66	282.09	0.24	-0.59
NO_2	156	5.59	81.17	29.47	15.66	1.58	1.88

Unit all the parameters is in mg/l except *EC* ($s/cm^{-1} x\ 10^{-3}$) and *pH*, N=Total number of samples

The mean concentration (599.52 mg/l) as well as standard deviation (154.72 mg/l) were high denoting a wide range of concentration throughout the space. Skewness and kurtosis showed small and positive values of +0.66 and +1.59 respectively. Skewness showed left skewed distribution indicating the concentration on the right side of the mean with extreme values to the left. Kurtosis indicates platy distribution flatter than the normal distribution. Up to the depth of 90 mbgl the concentration of *TDS* ranged between 400 mg/l and 600 mg/l (Fig. 3.7).

Pre-monsoon Season (Total Dissolved Soilids)

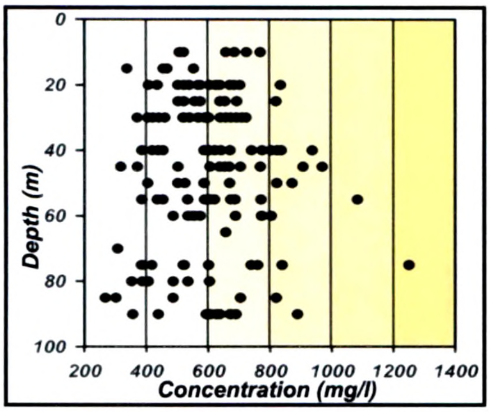


Fig. 3.6 Concentration

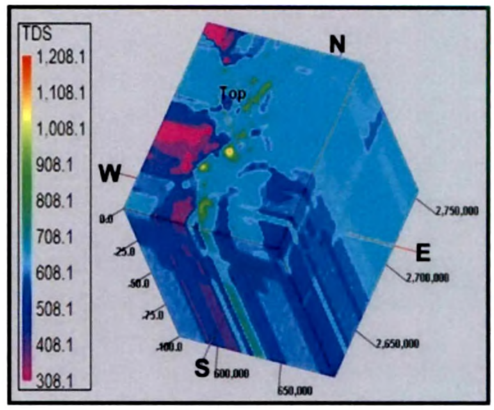


Fig. 3.7 Distribution

Pre-monsoon Season (Electrical Conductivity)

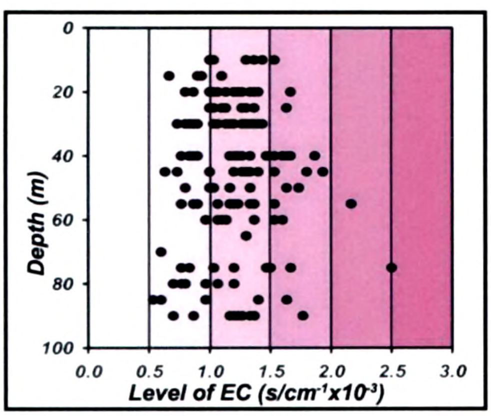


Fig. 3.8 Concentration

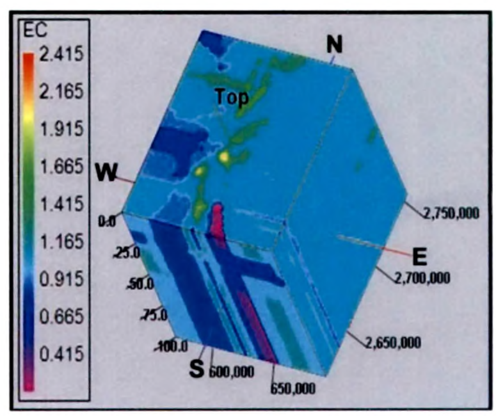


Fig. 3.9 Distribution

The level of *EC* varied from 0.53 $s/cm^{-1}x\ 10^{-3}$ to 2.50 $s/cm^{-1}x\ 10^{-3}$ and with mean of 1.19 $s/cm^{-1}x\ 10^{-3}$ (Fig. 3.8).

The standard deviation also indicated relatively lesser variability (0.31 $s/cm^{-1}x\ 10^{-3}$) of *EC* throughout the space. Skewness and kurtosis were associated with very low and positive values of +0.68 and +1.69 respectively. The level of *EC* at the greater depth showed relatively lower values (Fig. 3.9). The concentration of *iron* ranged between 0.70 mg/l and 82.32 mg/l (Fig. 3.10). The mean value was considerably low (7.78 mg/l), indicating a relatively small variation in the level of concentration.

Standard deviation was 10.79 mg/l, while skewness and were positive with considerably high values (+3.64 and +16.70 respectively).

Pre-monsoon Season (Iron)

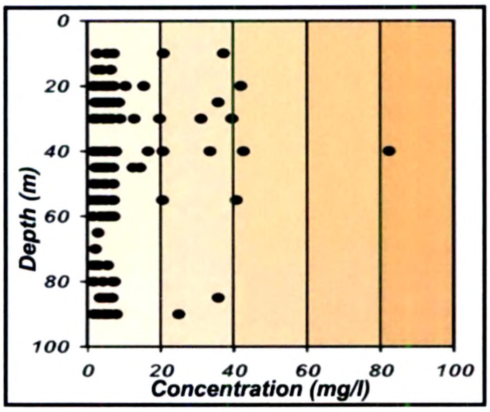


Fig. 3.10 Concentration

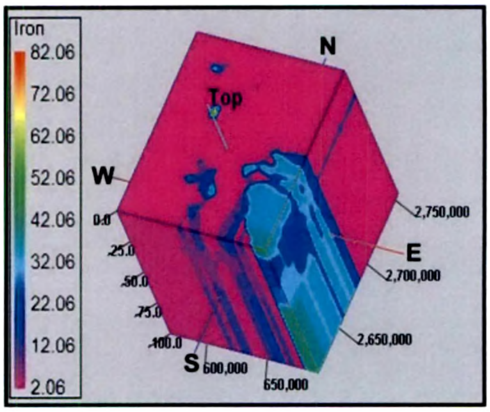


Fig. 3.11 Distribution

Pre-monsoon Season (Chloride)

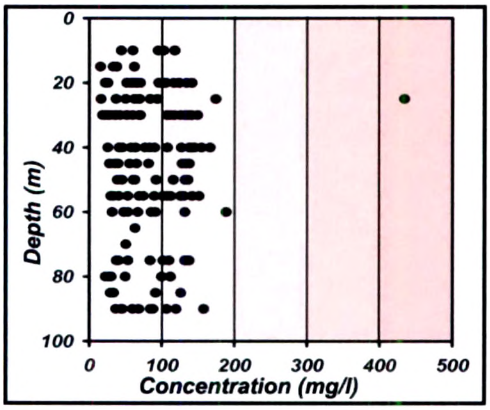


Fig. 3.12 Concentration

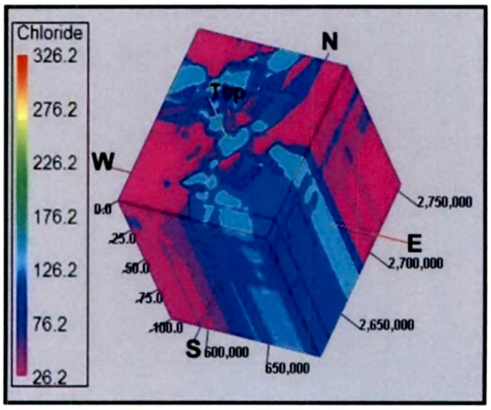
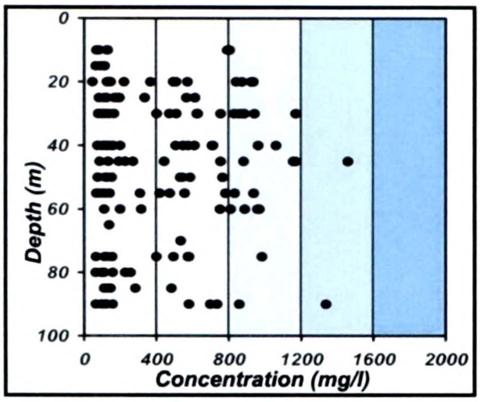


Fig. 3.13 Distribution

Depth wise variation in *iron* showed concentration ranging from 42 mg/l to 22 mg/l up to the depth of 90 mbgl (Fig. 3.11).

The concentration of *chloride* ranged between 15.23 mg/l to 434.13 mg/l. The mean and deviation values were 82.78 mg/l and 50.58 mg/l respectively (Fig. 3.12), indicating a considerably lesser variability. Skewness and kurtosis again were positive with moderate values of +2.29 and +13.49 respectively and was found at the greater depth (Fig. 3.13).

Pre-monsoon Season (Sulfate)



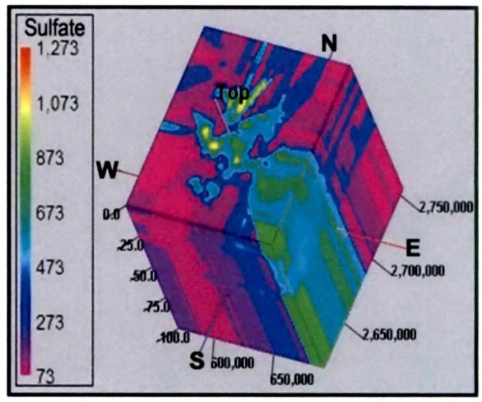
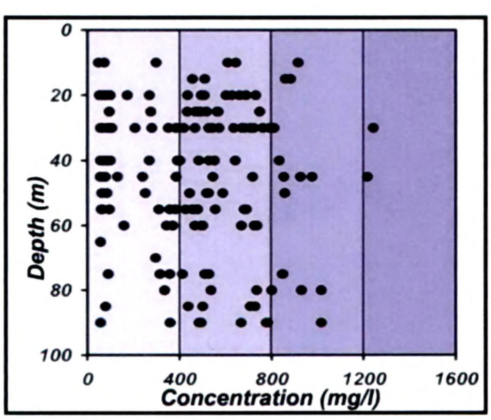


Fig. 3.14 Concentration **Fig. 3.15 Distribution**

The concentration of *sulfate* varied from 45.87 mg/l to 1458.87 mg/l (Fig. 3.14). Both mean (395.72 mg/l) as well as the standard deviation were high (339.58 mg/l). Skewness and kurtosis showed very low values with former, positive (+0.89) while later, negative (-0.32) and it was observed to a considerable level up to 90 mbgl (Fig. 3.15).

Pre-monsoon Season (Total Hardness as $CaCO_3$)



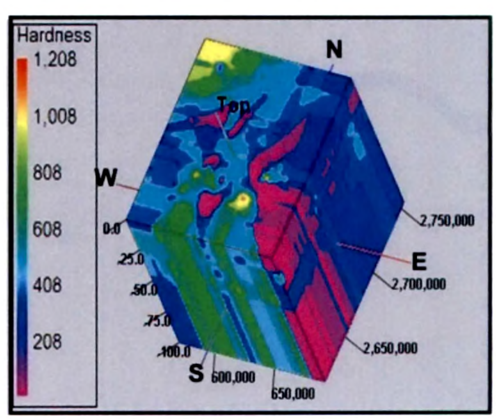


Fig. 3.16 Concentration **Fig. 3.17 Distribution**

The concentration of *total hardness as* $CaCO_3$ had a minimum of 48.03 mg/l and maximum of 1242.33 mg/l (Fig. 3.16). The mean (449.66 mg/l) and standard deviation (282.09 mg/l) were high. Skewness and kurtosis had low values but former was positive (+0.24) while the later negative (-0.59). The concentration of 208 mg/l to 808 mg/l was found in up to 90 mbgl depth (Fig. 3.17).

The concentration of *nitrite* varied from 5.59 mg/l to 81.17 mg/l (Fig. 3.18).

Pre-monsoon Season (Nitrite)

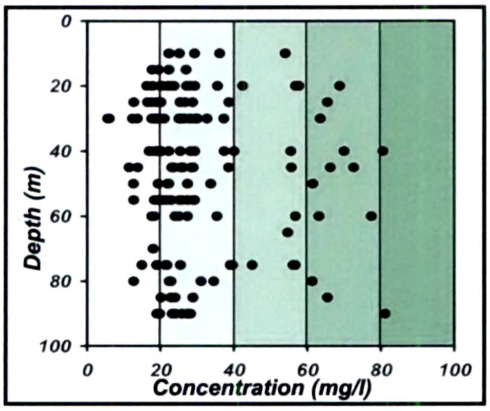


Fig. 3.18 Concentration

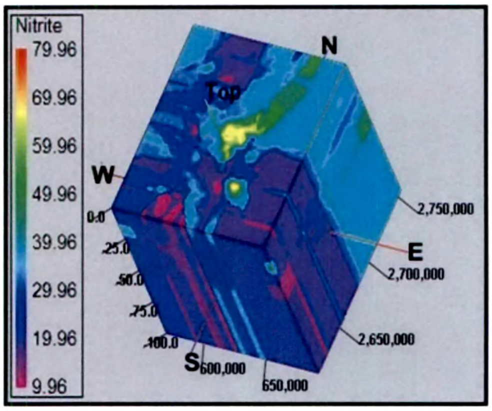


Fig. 3.19 Distribution

The mean concentration was 29.47 mg/l and the deviation from mean was considerably low (15.66mg/l). Skewness and kurtosis showed considerably low positive values at +1.58 and +1.88 respectively. Fig. 3.19 depicted that the concentration of the element is largely restrained at the shallower depth.

3.2.2. Monsoon:

The concentration of *arsenic* during the monsoon season varied between BDL and 0.33mg/l (Fig 3.20) and even found in the depth between 50 mbgl – 90 mbgl (Fig. 3.21). The mean concentration was 0.03 mg/l and the low variability of concentration 0.04 mg/l was observed. Skewness and kurtosis showed very high and positive values of +4.99 and +31.28 respectively. The level of *pH* indicated a wide range from the acidic (6.77) to alkaline condition (8.67) (Fig. 3.22). A slight deviation from the mean value was observed (0.37).

Small values of skewness and kurtosis were observed but former was positive (+0.47) and later negative (-0.15). In the entire region, the level of *pH* in the greater depth ranged between 6 -7 (Fig. 3.23).

Monsoon Season (Arsenic)

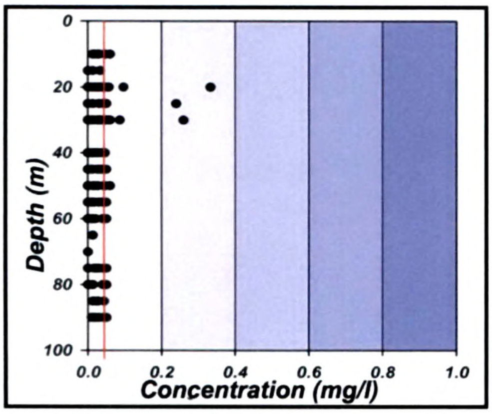


Fig. 3.20 Concentration

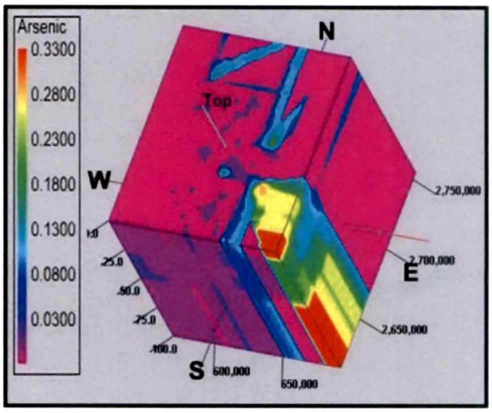


Fig. 3.21 Distribution

Monsoon (pH)

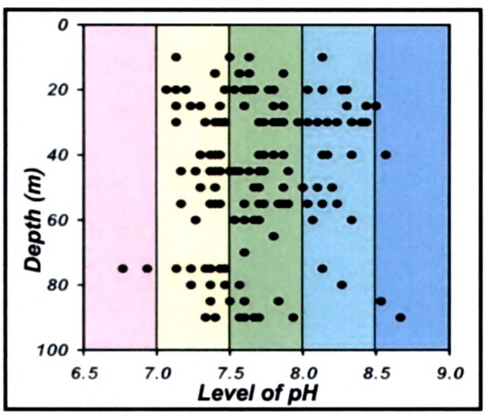


Fig. 3.22 Concentration

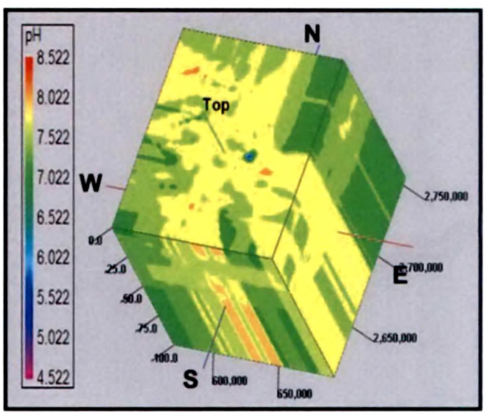


Fig. 3.23 Distribution

The concentration of *TDS* ranged between 183.83 mg/l to 982 mg/l denoting a high range (477.08 mg/l) (Fig. 3.24). The higher deviation from mean (135.68 mg/l) indicated spatial variability (Fig. 3.25). Skewness and kurtosis showed very low and positive values of +0.35 and +0.72 respectively.

Monsoon Season (Total Dissolved Solids)

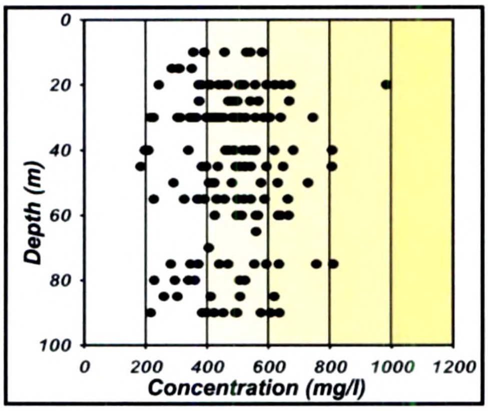


Fig. 3.24 Concentration

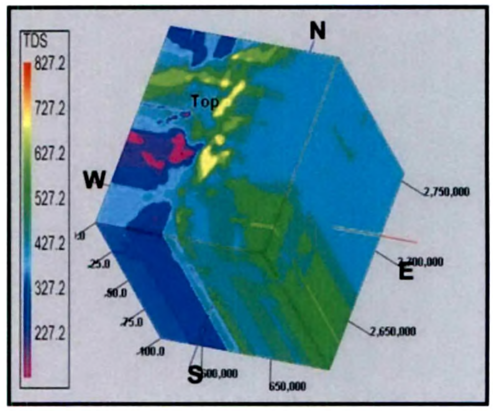


Fig. 3.25 Distribution

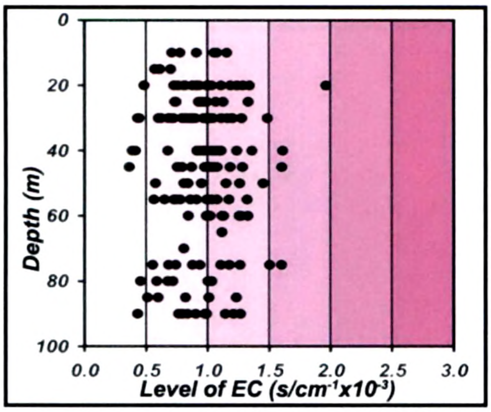
Table : 3.2 Descriptive statistics of Groundwater Parameters during Monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.33	0.03	0.04	4.99	31.28
pH	156	6.77	8.67	7.68	0.37	0.47	-0.15
TDS	156	183.83	982.00	477.08	135.68	0.35	0.72
EC	156	0.36	1.96	0.95	0.27	0.36	0.72
Iron	156	1.00	50.44	7.68	9.21	2.45	6.64
Chloride	156	27.50	284.83	98.32	46.16	0.86	1.12
Sulfate	156	32.27	1297.47	217.69	261.81	2.11	4.07
Total Hardness as $CaCO_3$	156	50.20	1050.43	524.74	254.39	-0.08	-0.78
NO_2	156	7.52	69.50	25.51	12.01	1.69	2.89

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*, N=Total number of samples

The level of *EC* had a minimum of 0.36 s/cm^{-1}x 10^{-3} and maximum of 1.96 s/cm^{-1}x 10^{-3} (Fig. 3.26). The mean was 0.95 s/cm^{-1}x 10^{-3} and deviation from mean was 0.27 s/cm^{-1}x 10^{-3}. Skewness and kurtosis had low positive values of +0.36 and +0.72 respectively. *EC* depicted lower values at greater depth in the entire region (Fig. 3.27) (Table 3.2).

Monsoon Season (Electrical Conductivity)



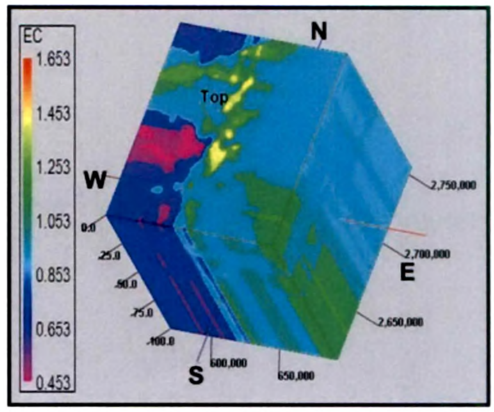
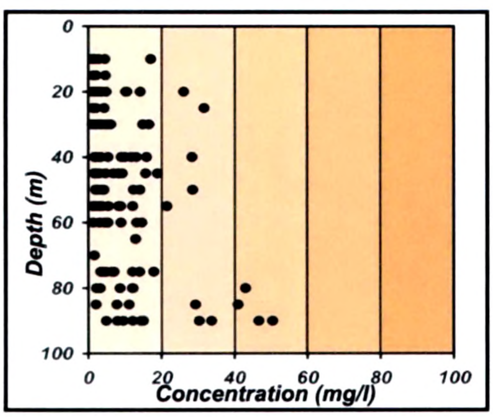


Fig. 3.26 Concentration

Fig. 3.27 Distribution

Monsoon Season (Iron)



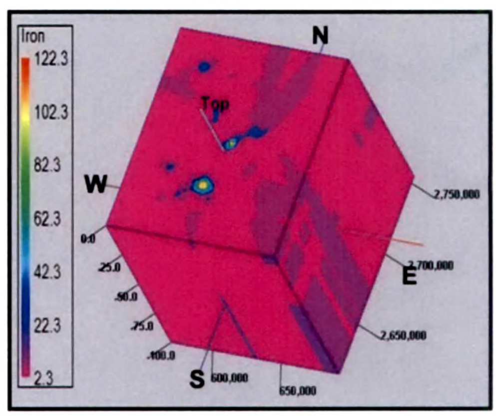


Fig. 3.28 Concentration

Fig. 3.29 Distribution

The concentration of *iron* varied between 1.00 mg/l to 50.44 mg/l (Fig. 3.28). The mean concentration of *iron* was 7.68 mg/l and depicted a considerably less deviation from mean (9.21 mg/l) throughout the space while it did not show any significant variation at greater depths (Fig. 3.29). Skewness and kurtosis showed moderate and positive value of +2.45 and +6.64 respectively. The concentration of *chloride* varied between 27.50 mg/l and 284.83 mg/l (Fig. 3.30). The mean concentration was 98.32 mg/l while deviation from mean was 46.16 mg/l.

Monsoon Season (Chloride)

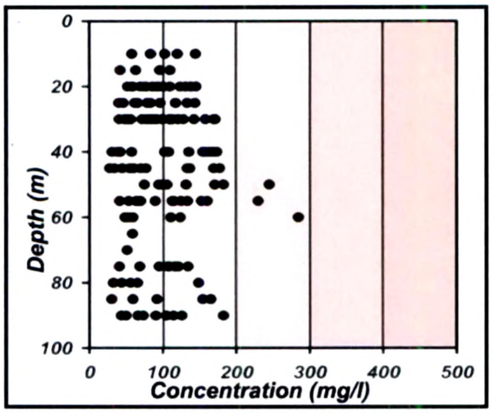


Fig. 3.30 Concentration

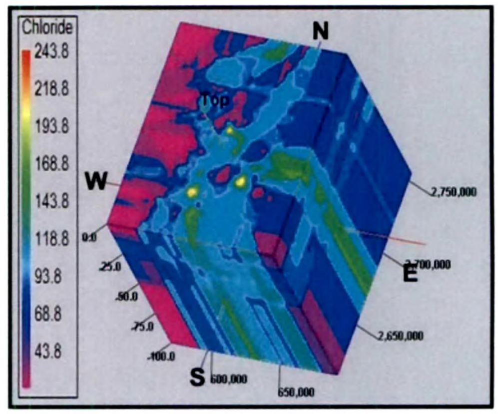


Fig. 3.31 Distribution

Monsoon Season (Sulfate)

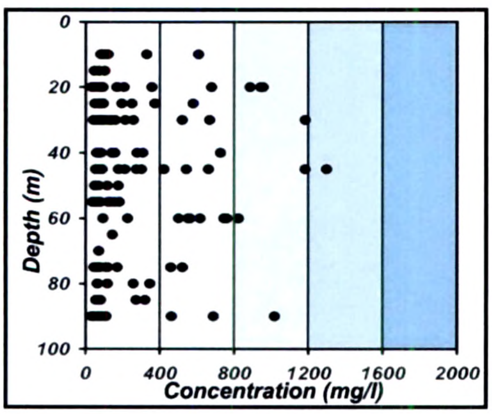


Fig. 3.32 Concentration

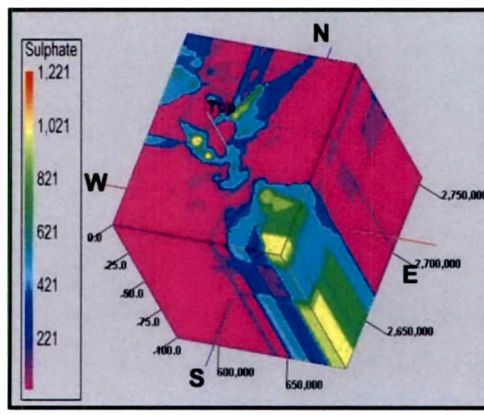
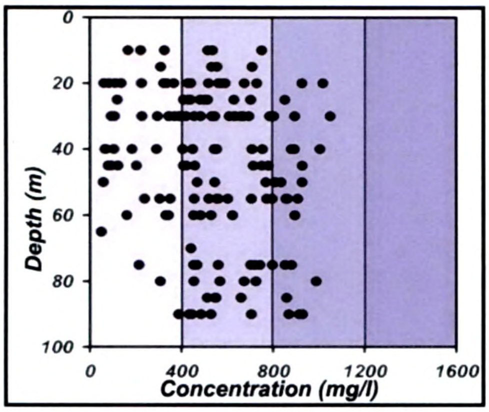


Fig. 3.33 Distribution

Skewness and kurtosis showed low and positive values of +0.86 and +1.12.Considerable variation in concentration in terms of depth was observed (Fig. 3.31).

The concentration of *sulfate* ranged from 32.27 mg/l to 1297.47 mg/l (Fig. 3.32). Although the range of data was very high but mean concentration was 217.69 mg/l indicating lesser variability of the *sulfate*. Standard deviation indicated higher deviation from mean (261.81 mg/l) while skewness and kurtosis showed moderate and

Monsoon Season (Total Hardness as $CaCO_3$)



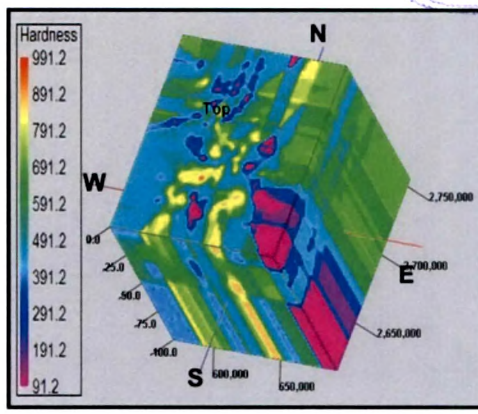


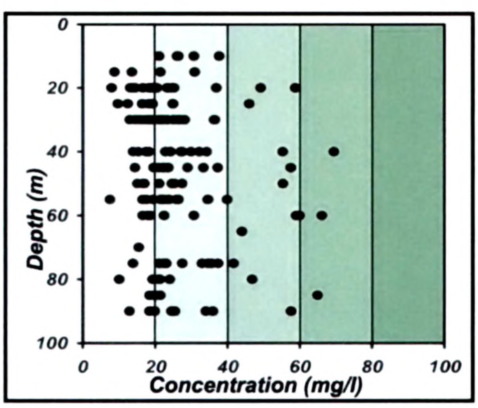
Fig. 3.34 Concentration

Fig. 3.35 Distribution

positive values (+2.11 and +4.07 respectively). The concentration was found as high as 1000 mg/l at the greater depths (Fig. 3.33).

The concentration of *total hardness as $CaCO_3$* ranged from 50.20 mg/l to 1050.43 mg/l (Fig. 3.34) with considerable variation in depth (Fig. 3.35). The mean concentration was 524.74 mg/l and the deviation from mean was high (254.39 mg/l).

Monsoon Season (Nitrite)



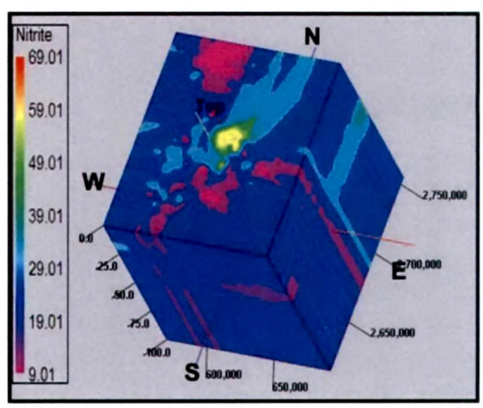


Fig. 3.36 Concentration

Fig. 3.37 Distribution

Skewness and kurtosis showed negative and low values (-0.08 and -0.78 respectively). The minimum concentration of *nitrite* was 7.52 mg/l and the maximum 69.50 mg/l. The mean dilution was 25.51 mg/l and deviation from mean was just 12.01 mg/l (Fig. 3.36) with less variation in depth (Fig. 3.37). Skewness and kurtosis were low and positive (+1.69 and +2.89 respectively).

3.2.3. Post-monsoon:

The concentration of *arsenic* during post-monsoon season ranged between BDL to 0.81mg/l (Fig. 3.38) with higher concentration up to depth of 90 mbgl (Fig. 3.39). The mean concentration of *arsenic* was 0.06 mg/l which is considerably higher than the

Post-monsoon Season (Arsenic)

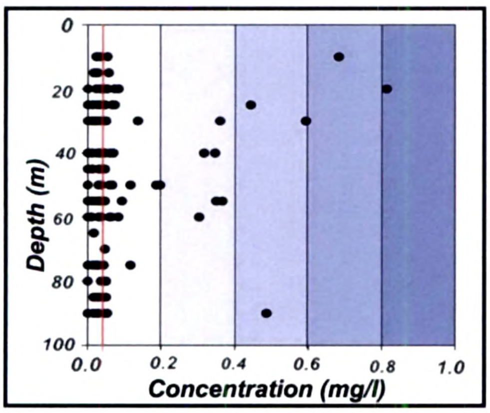


Fig. 3.38 Concentration

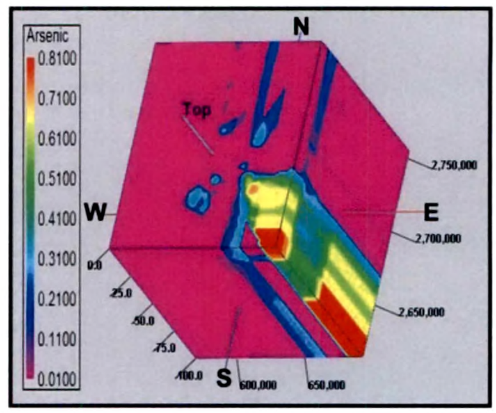


Fig. 3.39 Distribution

permissible limit. The standard deviation was 0.12 mg/l indicating very little variation. Skewness and kurtosis showed high and positive values (+3.85 and +16.24 respectively).

Post-monsoon Season (pH)

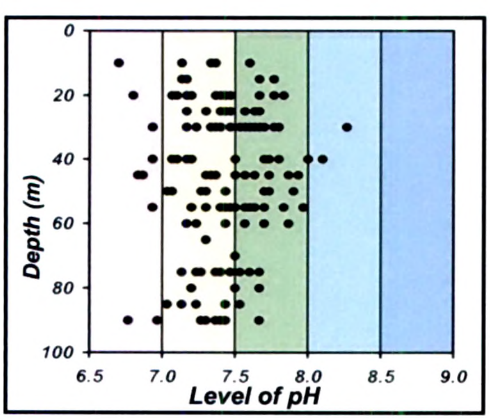


Fig. 3.40 Concentration

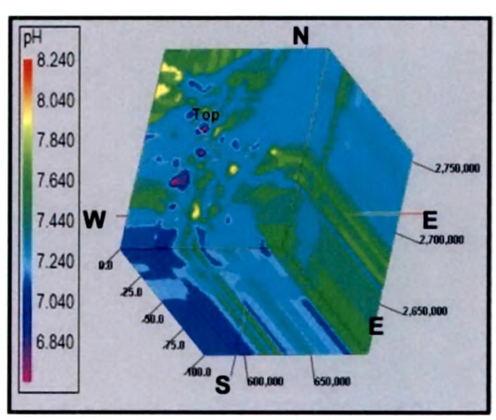


Fig. 3.41 Distribution

The level of *pH* ranged from acidic (6.70) to alkaline (8.27) condition (Fig. 3.40). The mean depicted slightly alkaline condition (7.43) spatially as well as vertically (Fig. 3.41). Not much variation was observed in *pH* values in terms of standard deviation (0.27). Skewness was -0.02, while kurtosis was positive and moderate (+0.28).

Post-monsoon Season (Total Dissolved Solids)

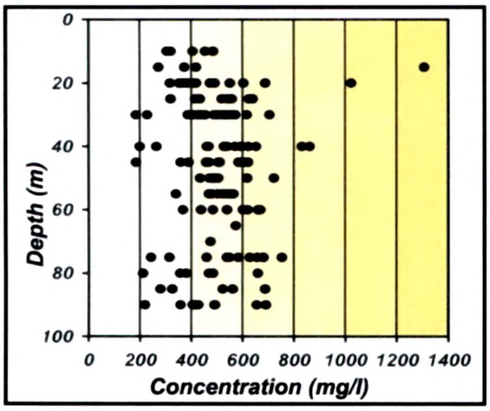


Fig. 3.42 Concentration

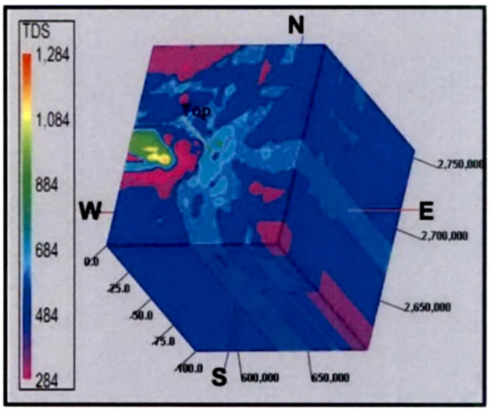


Fig. 3.43 Distribution

The concentration of *TDS* ranged from 183.43 mg/l to 1305.90 mg/l (Fig. 3.42) mainly confined to shallower depth (Fig. 3.43). The mean concentration was 494.51 mg/l

Post-monsoon Season (Electrical Conductivity)

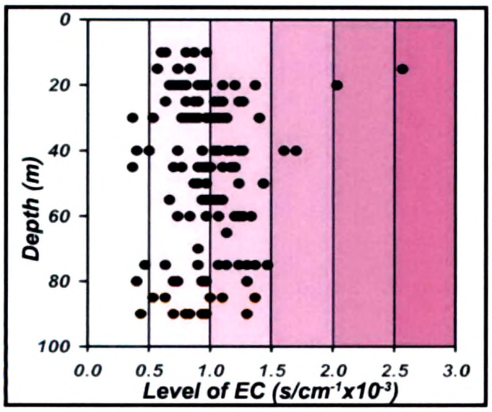


Fig. 3.44 Concentration

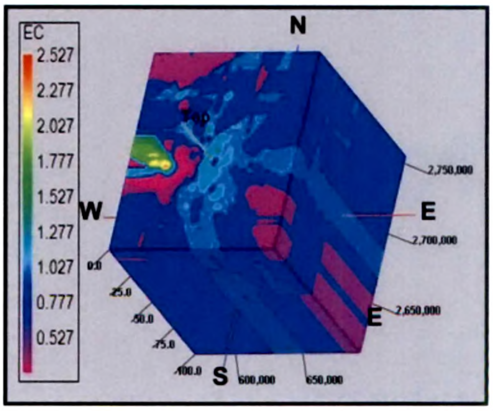


Fig. 3.45 Distribution

and the deviation from the mean was 145.44 mg/l. Skewness and kurtosis were positive and moderate (+1.30 and +6.39 respectively).

Table : 3. 3 Descriptive statistics of Groundwater Parameters during Post-monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.81	0.06	0.12	3.85	16.24
pH	156	6.70	8.27	7.43	0.27	-0.02	0.28
TDS	156	183.43	1305.90	494.51	145.44	1.30	6.39
EC	156	0.37	2.57	0.97	0.29	1.35	6.46
Iron	156	1.10	36.84	8.21	6.51	1.87	3.92
Chloride	156	12.23	173.80	82.44	40.25	0.34	-1.05
Sulfate	156	50.33	1679.80	445.84	352.79	0.87	-0.22
Total Hardness as $CaCO_3$	156	55.37	970.27	420.22	208.66	0.40	-0.54
NO_2	156	10.21	58.03	25.64	8.61	1.27	2.32

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*, N=Total number of samples

Post-monsoon Season (Iron)

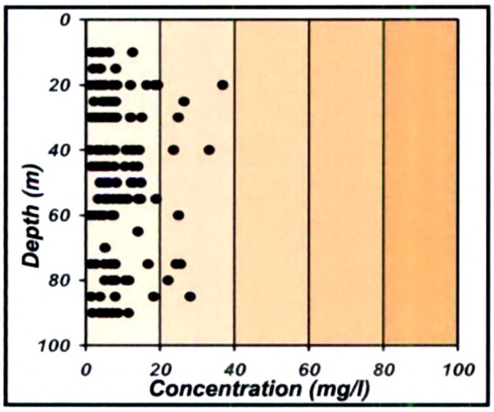


Fig. 3.46 Concentration

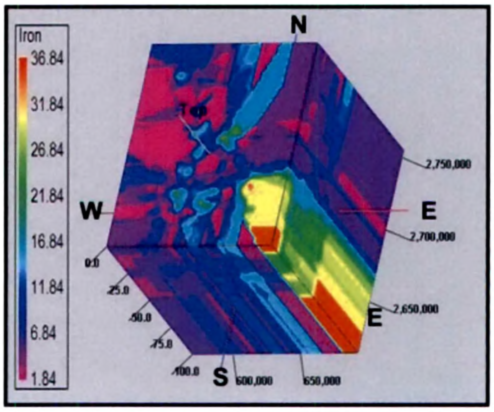


Fig. 3.47 Distribution

Post-monsoon Season (Chloride)

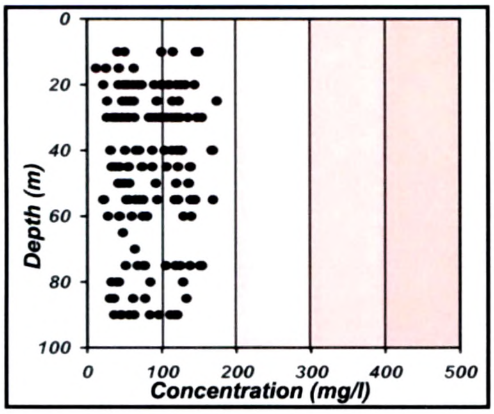


Fig. 3.48 Concentration

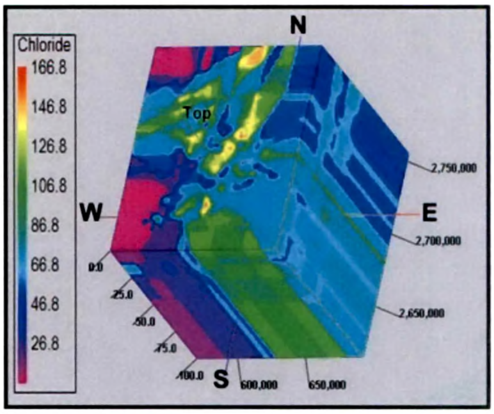


Fig. 3.49 Distribution

The concentration of *iron* ranged from 1.10mg/l to 36.84 mg/l (Fig.3.46) with a low mean of 8.21mg/l and higher concentration in greater depth (90 mbgl) (Fig.3.47). Deviation from the mean was small (6.51 mg/l). Skewness and kurtosis indicated low and positive values of +1.87 and +3.92 respectively.

Post-monsoon Season (Sulfate)

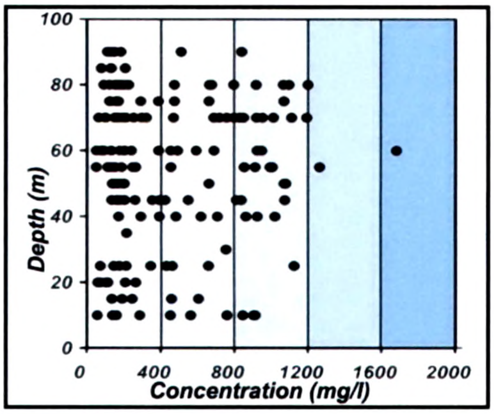


Fig. 3.50 Concentration

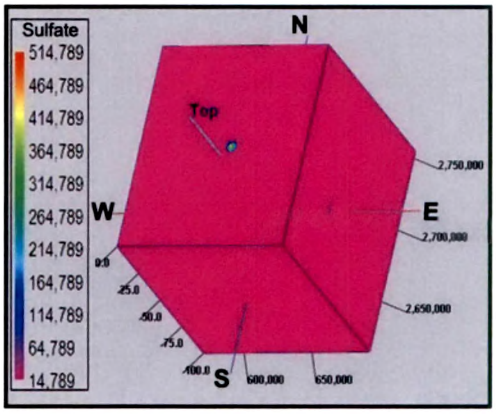


Fig. 3.51 Distribution

The minimum concentration of *chloride* was 12.23 mg/l while the maximum was 173.80 mg/l (Fig. 3.48) with a mean of 82.44 mg/l and moderate concentration considerable depth (90 mbgl) (Fig. 3.49). Standard deviation was 40.25 indicating a moderate deviation from the mean. Skewness (+0.34) and kurtosis (-1.05).

The concentration of *sulfate* varied between 50.33 mg/l to 1679.80 mg/l (Fig. 3.50) with moderate mean of 445.84 mg/l and very less vertical variation (Fig. 3.51). Deviation from the mean was also moderate (352.79 mg/l). Skewness was positive (+0.87) while kurtosis had a negative value of -0.22.

Post-monsoon Season (Total Hardness as $CaCO_3$)

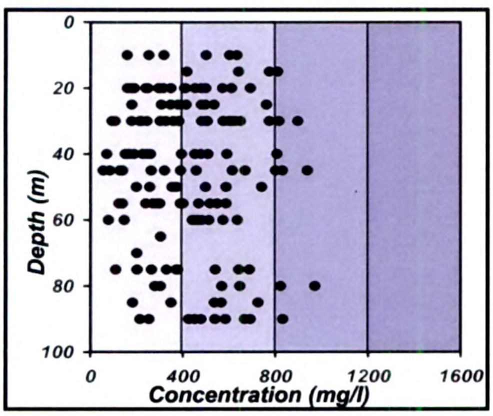


Fig. 3.52 Concentration

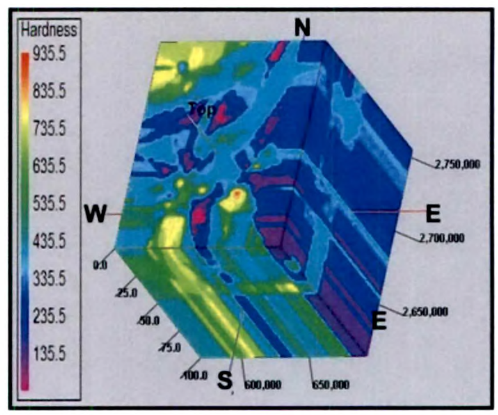


Fig. 3.53 Distribution

The concentration of *total hardness as $CaCO_3$* varied between 55.37mg/l and 970.27mg/l (Fig. 3.52) with considerable higher concentration up to depth of 90 mbgl (Fig. 3.53). The mean concentration was 420.22mg/l and the deviation from the mean was 208.66. Skewness and kurtosis indicated positive low values of +0.40 and -0.54 respectively.

The concentration of *nitrite* ranged from 10.21 mg/l to 58.03 mg/l (Fig. 3.54). The mean concentration was 25.64 mg/l while standard deviation of 8.61, depicting low deviation from the mean. Skewness and kurtosis were positive (+1.27 and +2.32 respectively). Concentration of the parameters can be traced up to the depth of 90 mbgl (Fig. 3.55).

Post-monsoon Season (Nitrite)

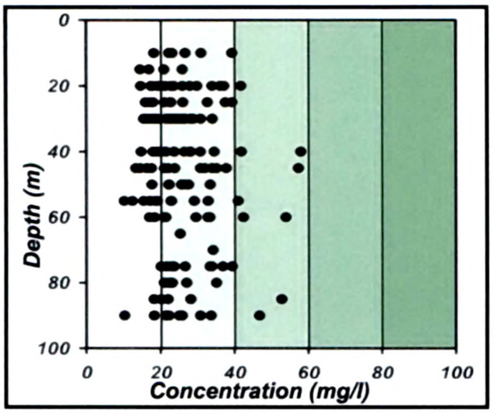


Fig. 3.54 Concentration

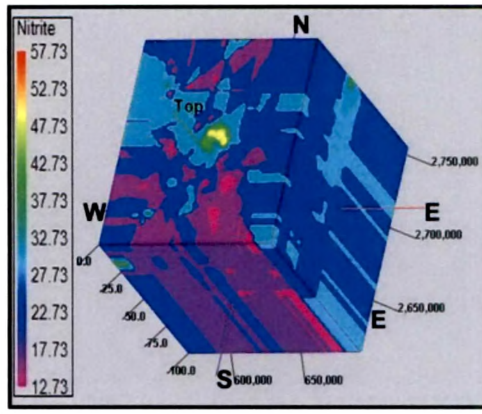


Fig. 3.55 Distribution

3.3 Factor analysis:

With increasing number of variables, the interrelationships among them becomes much more complex. Factor analysis is a type of multivariate statistical analysis which helps in identifying the internal similarity of data set (**Davis**, 1986, **Cloutier**, et al. 2008). The main aim of this type of analysis is to reduce the dimensionality of the data set and reproduce set of interrelated variable without losing any information (**Farnham** et al. 2002). In the present study, factor analysis technique was applied by using **"Kaiser Criterion"** where eigenvalues more than 1 were retained (**Davis**, 1986). Decreasing eigenvalues were plotted against the factor number to obtain scree plot. The break in the scree plot signified the number of factor to be taken into considerations. For ensuring maximum variability of the data **'varimax'** rotation technique was applied. The factor depicted through the analysis, grouped the larger number of variables into smaller ones, which can be analyzed and interpreted in a much efficient way.

3.3.1. Pre-monsoon season:

Four important factors showed 62.194% of the total variability of the data set (Table 3.4).

Table: 3.4 Total Variance Explained by Factor Analysis during Pre-monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.351	23.510	23.510	2.351	23.510	23.510
2	1.677	16.769	40.279	1.677	16.769	40.279
3	1.146	11.461	51.740	1.146	11.461	51.740
4	1.045	10.454	62.194	1.045	10.454	62.194
5	0.928	9.283	71.477			
6	0.840	8.400	79.877			
7	0.787	7.870	87.748			
8	0.650	6.498	94.246			
9	0.575	5.753	99.999			
10	0.000	0.001	100.000			

Extraction Method: Principal Component Analysis.

Table: 3.5 Rotated Component Matrix of Pre-monsoon season (2010-2012)

Parameters	Factors			
	1	2	3	4
Arsenic	0.064	**-0.684**	0.312	-0.067
Depth	0.000	**0.678**	0.097	-0.095
pH	0.220	-0.169	-0.407	**0.484**
TDS	**0.963**	-0.079	0.000	0.078
EC	**0.964**	-0.079	0.002	0.077
Iron	-0.225	-0.338	0.203	**0.564**
Chloride	0.169	0.187	0.207	**0.784**
Sulfate	0.124	0.094	**0.692**	0.193
Total Hardness as $CaCO_3$	-0.020	0346	**-0.696**	-0.055
NO_2	**0.497**	0.352	0.220	-0.021

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

Similar pattern was observed through the scree plot where number of factors above the eigenvalues of 1 were four (Fig. 3.56). The first factor depicted 23.510% of the variability of the data set,

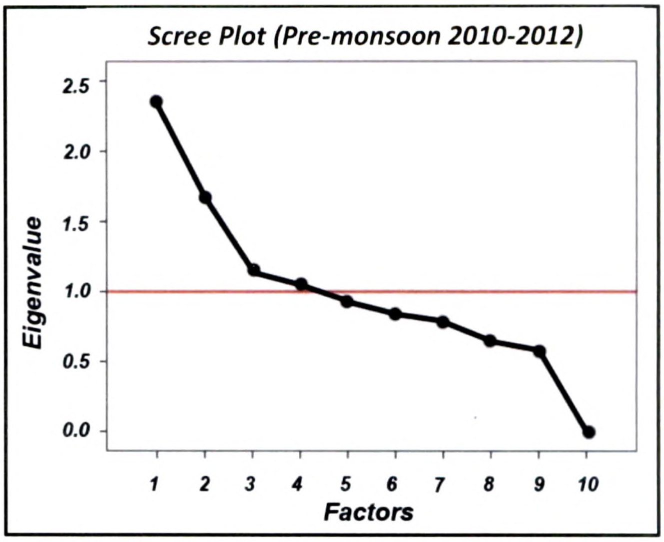


Fig. 3.56: Scree Plot of pre-monsoon season

followed by second factor (16.769%) third 11.461% and fourth 10.454%. Factor 1 was associated with *TDS*, *EC* and *nitrite* parameters with loadings of +0.963, +0.964 and +0.497 respectively (Table 3.5). *Arsenic* and *depth* with loadings of -0.684 and +0.678 respectively were found in Factor 2. The third factor was *sulfate* and *total hardness as* $CaCO_3$ with loadings of +0.692 and -0.696 respectively. The last factor associated *pH*, *iron* and *chloride* had loadings of +0.484, + 0.564 and +0.784 respectively.

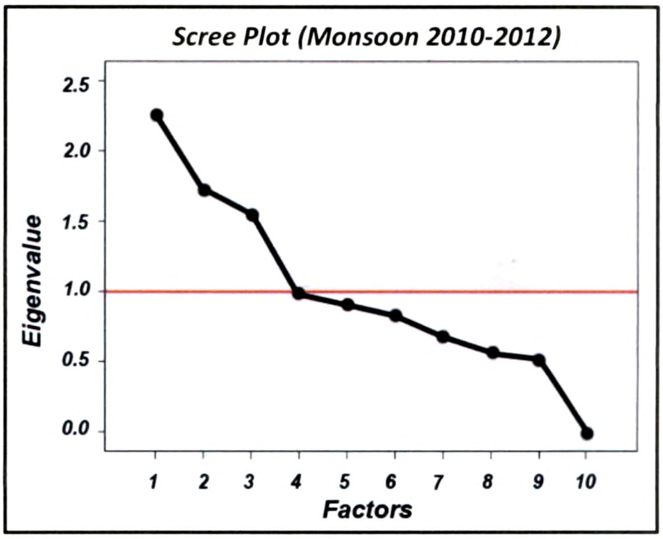


Fig. 3.57: Scree Plot of monsoon season

3.2.2. Monsoon season:

During the monsoon season the data set had a total variability of 65.079%. The first factor represents 22.50% of variability while the other three factors had 17.270%, 15.479% and 9.860% of variability (Table. 3.6) (Fig. 3.57). The first factor with parameters of *TDS* and *EC* had very high loadings of +0.963 and +0.965 respectively.

The second factor is associated with the parameters of *depth, chloride, sulfate* and *total hardness as $CaCO_3$*. *Depth* and *sulfate* show positive loadings (+0.548 and +0.734 respectively) while *chloride* and *total hardness as $CaCO_3$* had negative loadings (-0.426 and -715 respectively). *Arsenic* and *iron* are the third factors with high positive loadings (+0.794 and +0.840 respectively). The fourth factor showed highest loadings on *pH* (+0.858) and *nitrite* (-0.571).

Table: 3.6 Total Variance Explained by Factor Analysis during Monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.250	22.500	22.505	2.250	22.505	22.505
2	1.727	17.270	39.774	1.727	17.270	39.774
3	1.548	15.479	55.254	1.548	15.479	55.254
4	0.986	9.860	65.079	0.986	9.826	65.079
5	0.906	9.060	74.149			
6	0.822	8.229	82.378			
7	0.678	6.784	89.172			
8	0.564	5.641	94.814			
9	0.511	5.170	99.993			
10	0.001	0.007	100.000			

Extraction Method: Principal Component Analysis.

Table: 3.7 Rotated Component Matrix of Monsoon season (2010-2012)

Parameters	Factors			
	1	2	3	4
Arsenic	0.000	-0.186	**0.794**	-0.105
Depth	0.108	**0.548**	-0.140	0.099
pH	0.220	0.107	0.046	**0.858**
TDS	**0.963**	0.040	-0.043	-0.002
EC	**0.965**	0.038	-0.043	0.000
Iron	-0.061	0.027	**0.840**	-0.003
Chloride	0.420	**-0.426**	0.019	0.123
Sulfate	0.125	**0.734**	0.194	-0.215
Total Hardness as $CaCO_3$	0.155	**-0.715**	0.152	-0.105
NO_2	0.335	0.148	0.277	**-0.571**

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

3.3.3. Post-monsoon season:

Table: 3.8 Total Variance Explained by Factor Analysis during Post-monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.273	22.727	22.727	2.273	22.727	22.727
2	1.593	15.934	38.661	1.593	15.934	38.661
3	1.221	12.209	50.870	1.221	12.209	50.870
4	1.113	11.132	62.002	1.113	11.132	62.002
5	0.995	9.948	71.950			
6	0.827	8.272	80.222			
7	0.754	7.536	87.758			
8	0.651	6.514	94.271			
9	0.568	5.681	99.952			
10	0.005	0.048	100.000			

Extraction Method: Principal Component Analysis.

During the post-monsoon season the four factors (Fig. 3.58) had 62.002% of the total variability of the dataset. The first factor had 22.727% of the variability followed by 15.934%, 12.209% and 11.132% (Table. 3.8). During the post monsoon season, factor 1 was associated with the parameters of *TDS* and *EC*, where the factor loadings were high and positive (+0.982 and +0.984 respectively) (Table. 3.9). The second factor included *chloride,*

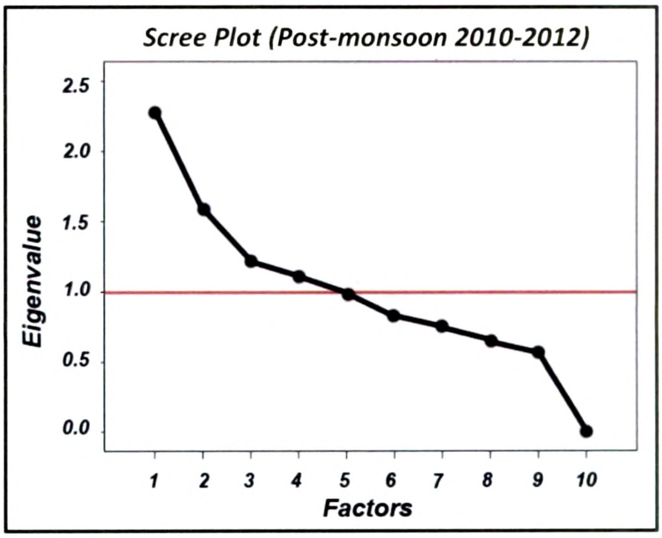


Fig. 3.58: Scree Plot of Post-monsoon season

sulfate and *total hardness as $CaCO_3$* with high loadings of +0.626 and 0.633 and -0.663 respectively. The third factor associated with

Table: 3.9 Rotated Component Matrix of Post-monsoon season (2010-2012)

Parameters	Factors			
	1	2	3	4
Arsenic	-0.010	-0.326	0.417	**0.425**
Depth	-0.051	0.243	-0.252	**0.599**
pH	0.110	0.127	**-0.703**	0.110
TDS	**0.982**	0.042	0.048	0.023
EC	**0.984**	0.038	0.036	0.024
Iron	0.081	0.064	0.038	**0.817**
Chloride	0.185	**0.626**	0.334	0.027
Sulfate	0.112	**0.633**	-0.040	0.059
Total Hardness as $CaCO_3$	0.195	**-0.663**	0.159	-0.134
NO_2	0.272	0.235	**0.702**	-0.015

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

pH and *nitrite* had high loadings (-0.703 and +0.702 respectively). The fourth factor composed of three major parameters (*arsenic, depth* and *iron*) with positive loadings of +0.425, +0.599 and +0.817 respectively. Table 3.10 depicted overall distribution of factors in different seasons.

Table: 3. 10 Distribution of Factor Score in Different Seasons

Factors \ Season	Pre-monsoon	Monsoon	Post-monsoon
1	TDS, EC and Nitrite	TDS and EC	TDS and EC
2	Arsenic and Depth	Depth, Chloride, Sulfate and Total Hardness as $CaCO_3$	Chloride, Sulfate and Total Hardness as $CaCO_3$
3	Sulfate and Total Hardness as $CaCO_3$	Arsenic and Iron	pH and Nitrite
4	pH, Iron and Chloride	pH and Nitrite	Arsenic, Depth and Iron

3.4. Inter-factorial Relationship:

Factors extracted from the factor analysis are a group of interrelated variables. It is widely used to understand the importance of each of the factors and their interdependence. Different combinations among the factors are taken into consideration for the analysis of the dynamics in the relationship between the factors.

3.4.1. Pre-monsoon season:

Between factor 1 and 2, a positive relationship was observed between *TDS, EC, nitrite* and *depth* whereas it was negative with *arsenic*. Between factor 1 and 3 a positive association exists in *TDS, EC, nitrite* and *sulfate* and negative with *total hardness as* $CaCO_3$. Positive association was observed amongst all the parameters of factor 1 and 4. In factor 2 and 3 *total hardness as* $CaCO_3$ has negative connection with *depth* and *sulfate*. The relationship between factor 2 and 4 depict only negative association of *arsenic* with other parameters. The relationship between factor 3 and 4, positive association between *sulfate, pH, iron* and *chloride* but negative relationship with *total hardness as* $CaCO_3$.

3.4.2. Monsoon season:

During monsoon season, amongst factor 1 and 2, positive relationship was observed between *TDS and EC* with *depth* and *sulfate* while negative with *chloride* and *total hardness as* $CaCO_3$. The association between factor 1 and 3 was positive in all the parameters viz., *TDS, EC* with *iron* and *arsenic*. Factor 1 and 4 had positive relationship on *TDS* and *EC* with *pH* and it was negative with *nitrite*. The bond between factor 2 and 3 was positive between *depth* and *sulfate* with *arsenic* and *iron* but negative with *chloride* and *total hardness as* $CaCO_3$. Similarly between factor 2 and 4 relationship was positive between *depth* and *sulfate* with *pH* while it was negative relation with *chloride, total hardness as* $CaCO_3$ with *nitrite*. The connection between factor 3 and factor 4 was positive between parameters of *arsenic* and *iron* with *pH* but negative with *nitrite*.

3.4.3. Post-monsoon season:

During the post-monsoon season, inter-factorial relationship between factor 1 and factor 2, depicted positive bond between *TDS* and *EC* with *chloride, sulfate,* while negative with *total hardness as* $CaCO_3$. Between factor 1 and 3, positive relationship existed among the parameters of *TDS* and *EC* with *nitrite* but negative with *pH*. The aassociation between factor 1 and 4 was positive in all the parameters of *TDS* and *EC* with *arsenic, depth* and *iron.* Between factor 2 and 3 positive relations in *chloride* and *sulfate* with *nitrite*, while negative in *total hardness as* $CaCO_3$ and *pH.* The link between factor 2 and 4 was negative with *total hardness as* $CaCO_3$, while it was positive in parameters of *chloride* and *sulfate* with *arsenic, depth* and *iron*. The association between the factor 3 and factor 4 was positive between the parameters of *nitrite* with *arsenic, depth* and *iron* but negative on *pH.*

3.5. Dynamics of factor scores:

Factor scores are the composites of the variables that are used to make the latent factor into an observed variable. The variation in the factor score during the seasons is one of the indicator of changes that are taking place in the geo-chemistry of the groundwater. Each factor scores were plotted in different seasons to understand the changing pattern of factors.

3.5.1. Factor score 1:

Factor score 1 distribution graph depicted the distribution of scores of the three seasons. Blocks like *Beldanga-2, Bhagwangloa-1, Bhagawangola-2* and *Jiagunj* showed very high factor scores (above 1) while *Bharatpur-1, Farakka, Khargram* and *Nabagram* had low factor scores (below -1). The graph depicted that in all the three seasons the pattern of the graph had similarity with each other (Fig. 3.59).

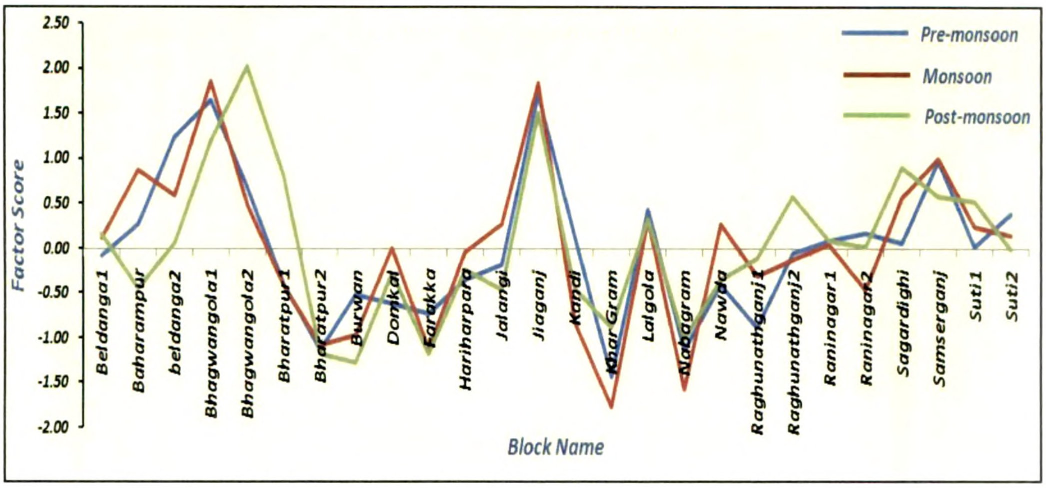


Fig. 3.59: Factor Score 1 Distribution in Different Seasons

3.5.2. Factor score 2:

Factor score 2 distribution graph showed that the blocks of *Beldanga-1, Domkal* and *Raghunathganj-2* had very high factor score (above 1) during pre-monsoon season.

During monsoon season all the blocks other than *Domkal* showed low factor scores (Fig. 3.60). During the post-monsoon season a very high peak can be seen in *Beldanga-1* and *Domkal* blocks where the factor score almost touches the score of 2. During post-monsoon season the blocks of *Samshergunj* showed very low factor score (below 1).

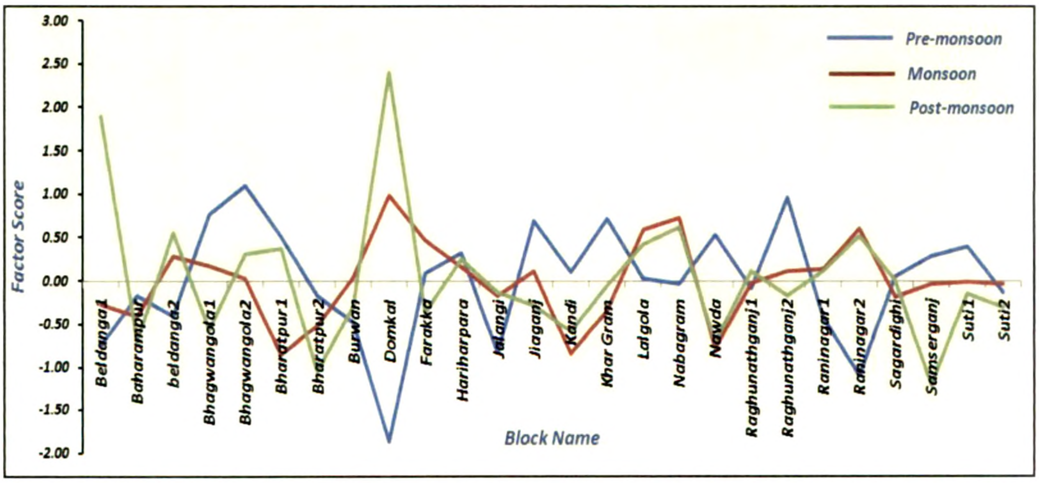


Fig. 3.60: Factor Score 2 Distribution in Different Seasons

3.5.3. Factor score 3:

Factor score 3 distribution graph depicts further variability in the pattern. During pre-monsoon season, very high peak can be observed in the blocks of *Domkal, Lalgola* and *Raghunathganj-2* while blocks of *Bhratpur-2, Farakka, Kandi* and *Samshergunj* showed very low factor score (below 1) (Fig. 3.61). During monsoon season *Bhagawangola-2* and *Raghunathganj-2* showed higher factor scores (above 1) while *Raninagar-2* touched scores of below -1.

During post-monsoon season factor – 3 had very high factor score for the blocks of *Berhampur, Jalangi* and *Lalgoal* (above +1). On the other hand, the blocks of *Khargram* and *Samshegunj* had very low factor scores (below-1).

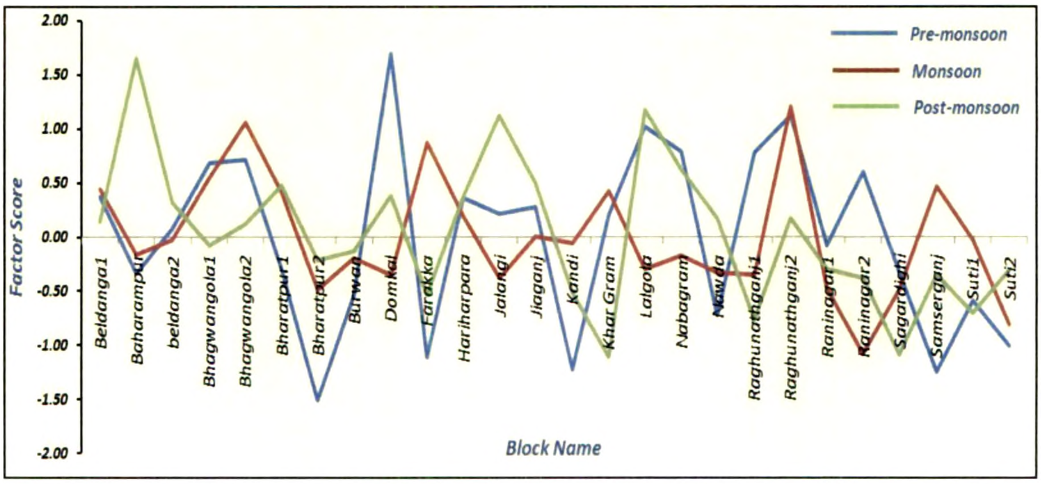


Fig. 3.61: Factor Score 3 Distribution in Different Seasons

3.5.4. Factor score 4:

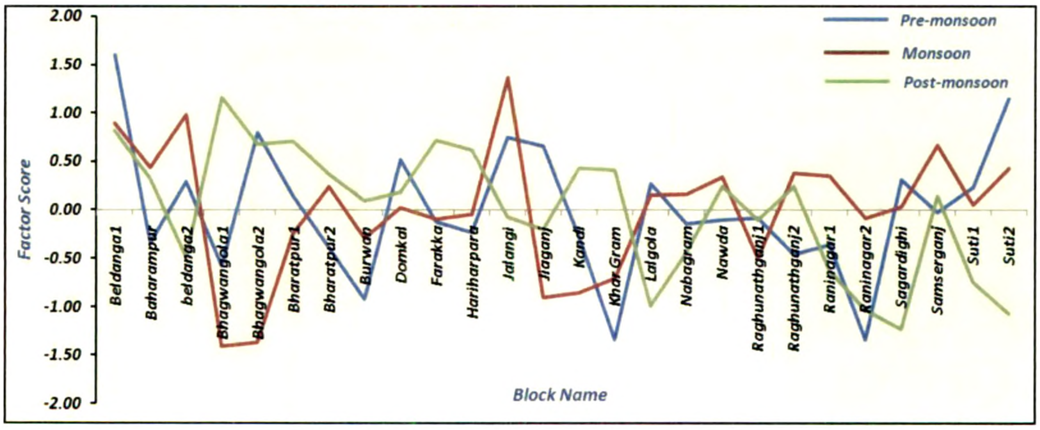


Fig. 3.62: Factor Score 4 Distribution in Different Seasons

During pre-monsoons season, factor score 4, had very high scores in the blocks of *Beldanga-1* (above +1). On the other hand, blocks of *Khragram, Buwan* and *Raninagar-2* showed very low factor score (below -1).

In monsoon season, *Beldanga-1, Beldanga-2* and *Jalangi* factor scores are illustrating very high factor scores (above +1) while *Bhagawangola-1, Bhagawangola*-2 and *Jiagunj* were the blocks which had very low factor scores (below -1) (Fig. 3.62). During post monsoon season *Bhagawangola-1* demonstrated high factor score while blocks of *Lalgola, Sagardighi* and *Suti-2* depicted low factor scores (below-1).

3.6 Cluster Analysis:

Cluster analysis is one of the important methods to combine hydrochemical data on the basis of *Euclidian Distance Method* having similar kind of characteristics (**Daughney** et al. 2012, **Kim** et al. 2009). Hierarchical Cluster Analysis is one of the clustering techniques which is widely used for cluster analysis (**Davis** 1986). Dendrogram is the representation of cluster analysis which showed the linkage of the sampling locations. In the present work, Ward's linkage agglomeration schedule coefficient was used to identify the number of clusters to be retained. Results obtained from the analysis, extracted four clusters. These clusters were further organized in their respective locations and isolines were generated using Inverse Distance Weighting method.

3.6.1. Pre-monsoon season:

Table: 3.11 Cluster Analysis of Pre-monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	NO_2	Nx
1	47.00	0.08	7.41	654.52	1.30	10.35	101.86	506.84	298.06	31.46	30.00
2	45.68	0.04	7.46	595.53	1.18	6.48	78.91	139.40	746.29	27.26	51.00
3	44.00	0.07	7.38	606.62	1.21	8.04	91.81	880.76	370.35	31.25	39.00
4	45.00	0.05	7.23	554.46	1.10	7.02	63.49	120.91	250.02	28.66	36.00

Unit of all the parameters is in mg/l except *EC*($s/cm^{-1} x 10^{-3}$) and *pH*,
Nx = total number of samples in the cluster

3.6.1.1 Cluster 1:

During pre-monsoon season 30 sampling locations were included in the cluster 1. In this cluster, the average *depth* to groundwater was 47 m and *arsenic* concentration was 0.08 mg/l. The average *pH* value depicted alkaline condition with a average value of 7.41. The level of *TDS* demonstrated the highest average concentration of 654.52 mg/l among all the clusters. Similar pattern was also observed in *EC* with average level of 1.30 s/cm^{-1}x 10^{-3}. The concentration of *iron* showed the highest average value of 10.35 mg/l which was highest among all the clusters. The concentration of *chloride* was as high as 101.86 mg/l. The concentration of *sulfate* showed moderate concentration of 506.84 mg/l and *total hardness as* $CaCO_3$ was as low as 298.06 mg/l. First cluster also had highest *nitrite* concentration 31.46 mg/l (Table 3.11). Most of the blocks located in the eastern and north central segment of the district (*Beldanga-1*, *Beldanga-2*, *Bhagawangola-1*, *Bhagawangola-2*, *Domkal, Hairharpara, Jiagunj, Nabagram, Raghunathganj-2* and *Raninagar-2)* were associated with cluster 1 (Fig. 3.63).

3.6.1.2 Cluster 2:

Cluster 2 is associated with relatively higher number of sampling locations (51). The average *depth* to the groundwater was 45.68 m, which was lower than the cluster 1. The average concentration of *arsenic* in this cluster was 0.04 mg/l which was below permissible limit set by BIS. The *pH* level of groundwater was 7.46 indicating a slight alkaline condition. The average concentration of *TDS* and *EC* were moderate in this cluster with concentration of 595.53 mg/l and 1.18 s/cm^{-1}x 10^{-3} respectively(Table 3.11). The concentration of *iron* and *chloride* in the cluster depicted least values of 6.48 mg/l and 78.91 mg/l respectively. *Sulfate* showed relatively low value of 139.40 mg/l while *total hardness* as $CaCO_3$ depicted highest concentration among all the clusters (746.29 mg/l). *Nitrite* also showed the least average concentration among all the clusters (27.26 mg/l). Spatially, it can be observed that, cluster 2 included major segments of *Bharatpur-1, Bharatpur-2, Farakka, Kandi, Bhagawangola, Suti-1, Suti-2 and Samshergunj* located in the northern and southern part of the district (Fig. 3.63).

3.6.1.3 Cluster 3:

This cluster consists of 39 sampling locations where an average *depth* of groundwater was 44 m and the average concentration of *arsenic* was 0.07mg/l indicating higher concentration. The level of *pH* showed slightly alkaline condition

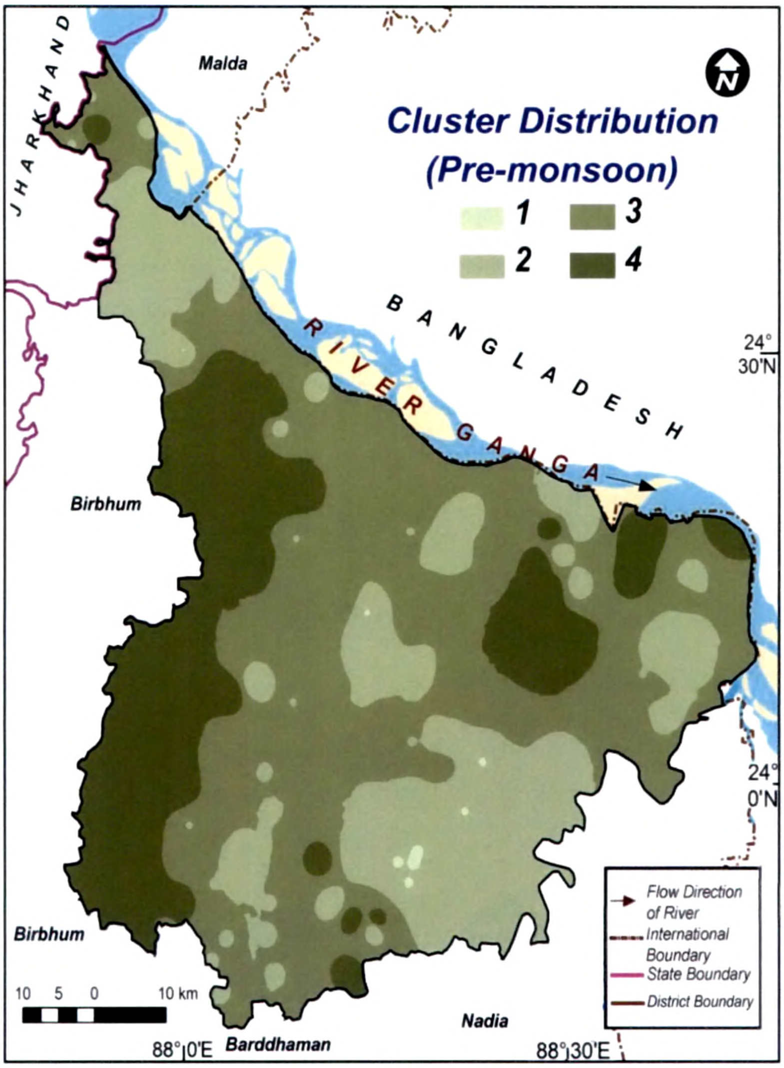


Fig. 3.63: Cluster Distribution during pre-monsoon season

(7.38) while higher concentration was observed in *TDS* and *EC* (606.62 mg/l and 1.21 s/cm^{-1}x 10^{-3} respectively). The average concentration of *iron* (8.04 mg/l) and *chloride* (91.81 mg/l) were considerably high. The concentration of *sulfate* was highest among all the clusters (880.76 mg/l). The concentration of *total hardness* as *CaCO3* and *nitrite* were moderate (370.35 mg/l and 31.25 mg/ l respectively) (Table 3.11). Spatially, it was observed that, this cluster was mostly confined in the north central as well as in the eastern segment of the district includeing blocks of *Behrampur, Bhagawangola-1, Bhagawangola-2, Domkal, Nabagram, Raghunathganj-2* (Fig. 3.63).

3.6.1.4 Cluster 4:

Fourth cluster incorporated 36 sampling locations and the average *depth* of the water was 45 m. The amount of *pH* was 7.23 and *arsenic* concentration was 0.05 mg/l. The concentration of *TDS* and *EC* were moderate (554.46 mg/l and 1.10 s/cm^{-1}x 10^{-3} respectively). The level of *iron, chloride, sulfate* and *total hardness as CaCO3* depicted least concentration (7.02 mg/l, 63.49 mg/l, 120.91mg/l and 250.02 mg/l respectively) (Table 3.11)whereas, concentration of *nitrite* was 28.66 mg/l. This cluster was located in the eastern and northern part of district including blocks of *Burwan, Khargram, Raghunathganj-1, Raninagar-1, Raningar-2* and *Sagardighi* (Fig. 3.63).

3.6.2 Monsoon season:

3.6.2.1 Cluster 1:

During the monsoon season, cluster 1 included 22 sampling locations. The average *depth* of water was 36.59 m. The maximum concentration of *arsenic* in this cluster was 0.11 mg/l. The level of *pH* showed slightly alkaline condition (7.34)

Table: 3.12 Cluster Analysis of Monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	No_2	Nx
1	36.59	0.11	7.34	675.72	1.34	6.58	81.47	287.41	168.56	30.26	22.00
2	44.32	0.05	7.35	529.54	1.05	9.10	80.22	251.99	448.26	24.47	59.00
3	48.52	0.09	7.40	634.52	1.26	6.29	88.44	824.04	430.05	37.10	27.00
4	49.27	0.03	7.41	630.93	1.25	7.54	83.33	381.11	591.23	30.96	48.00

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*,
Nx = total number of samples in the cluster

(Table.3.12). The concentration of *TDS* was 675.72 mg/l and of was *EC* 1.34 s/cm^{-1}x 10^{-3}. The concentration of *iron* (6.58 mg/l), *chloride* (81.47 mg/l), *sulfate* (287.41 mg/l), *total hardness as $CaCO_3$* (168.56 mg/l) and *nitrite* (30.26 mg/l) ranged from moderate to low. Spatially, the eastern and north western segment of the district were associated with this cluster that encompassed the blocks of *Beldanga-1, Beldanga-2, Raghunathganj-1, Raninagar-1, Raninagar-2* (Table 3.12) (Fig. 3.64).

3.6.2.2 Cluster 2:

Cluster 2 comprised of 59 sampling locations. In this cluster the average depth was 44.32 m and the average concentration of *arsenic* just touched the permissible limit of *arsenic* in groundwater (0.05 mg/l) (Red vertical line showed permissible limit of arsenic in Fig. 3.2, Fig. 3.20 and Fig. 3.38). The level of *pH* was almost same as cluster 1 with slight alkaline condition of 7.35. The level of *TDS* was 529.54 mg/l and that of *EC* of was 1.05 s/cm^{-1}x 10^{-3}. The concentration of *iron* was highest among all the clusters (9.10 mg/l) (Table 3.12). On the other hand, it was noticed that *chloride* and *sulfate* had least concentration of 80.22 mg/l and 251.99 mg/l respectively. The concentration of *total hardness as $CaCO_3$* was 448.26 mg/l and that of *nitrite* was 24.47 mg/l. This cluster comprised of *Beldanga-1, Burwan, Farakka, Raninagar-1, Raninagar-2, Suti-1 and Suti-2* blocks which were largely located in the western side of the *Murshidabad* district (Fig. 3.64).

3.6.2.3 Cluster 3:

Cluster 3 incorporated 27 sampling locations. The average *depth* of water in this cluster was 48.52 m while average *arsenic* concentration was 0.09mg/l. The level of *pH* showed slight alkaline condition (7.40). The mean concentration of *TDS was* 634.52 mg/l, *EC* 1.26 s/cm^{-1}x 10^{-3} and of *iron* 6.29 mg/l. *Chloride* and *sulfate* had a maximum concentration among all the clusters (88.44 mg/l and 824.04 mg/l respectively) (Table 3.12). The level of *total hardness as $CaCO_3$* had a moderate value of 430.05 mg/l while *nitrite* depicted maximum concentration of 37.10 mg/l. Major segments of *Domkal, Hariharpara, Raghunathganj-2* were included in this cluster which largely cover the north central portion of the study area (Fig. 3.64).

3.6.2.4 Cluster 4:

Fourth cluster which had 48 sampling locations had 49.27 m average *depth* of water. The mean *arsenic* concentration was as low as 0.03 mg/l while level of *pH* was highest among all the clusters (7.41). The concentration of *TDS* and *EC* were

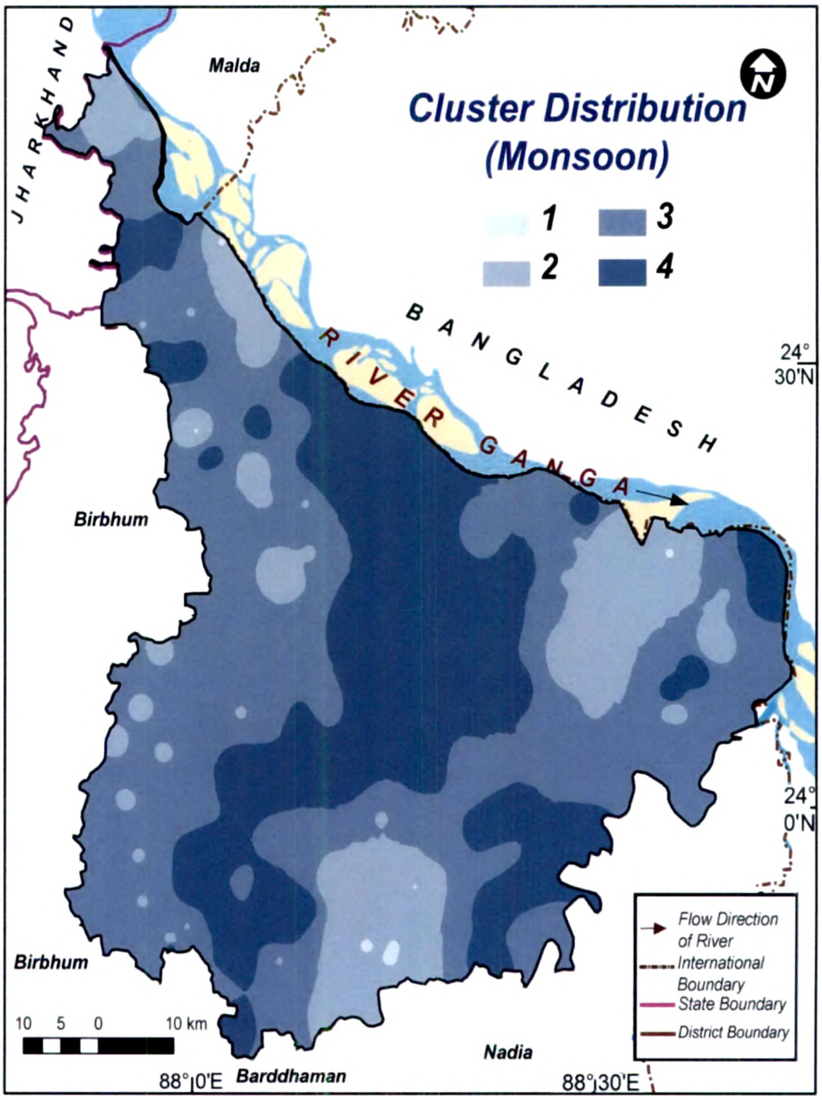


Fig. 3.64: Cluster Distribution during Monsoon Season

moderate (630.93 mg/l and 1.25 s/cm^{-1}x 10^{-3} respectively). The concentration of *iron*, *chloride* and *sulfate* were moderate (7.54 mg/l, 83.33 mg/l and 381.11 mg/l respectively) (Table 3.12). The concentration of *total hardness as $CaCO_3$* depicted highest value of 591.23 mg/l in all of the clusters while the concentration of *nitrite* showed moderate value of 30.96 mg/l. The blocks of *Beharmapur, Bhagawangola-1,* *Bhagawangola-2, Bharatpur- 1, Jiagunj, Raghunathganj-1, Raghunathganj-2* and *Shamsherganj* were associated with this cluster covering the northern and central segments of the district (Fig. 3.64).

3.6.3. Post-Monsoon:

3.6.3.1 Cluster 1:

During post monsoon, the cluster 1 incorporated 54 sampling locations. The average *depth* of groundwater was 46.76 m with higher concentration of *arsenic* (0.08 mg/l). The level of *pH* in cluster 1 was 7.36 which indicated a slight alkaline condition. The concentration of *TDS* and *EC* was as high as 593.45 mg/l and 1.18 $s/cm^{-1}x\ 10^{-3}$ respectively. The level of *iron* concentration was highest in this cluster (9.11 mg/l). The concentration of *chloride* and *sulfate was* moderate (88.14 mg/l and 208.24mg/l respectively). Average concentration of *total hardness as CaCO3* and *nitrite* was least in this cluster (297.85 mg/l and 27.03 mg/l respectively) (Table 3.13). Spatial distribution of the cluster showed concentration around the eastern as well as in the southern part of the study area. The blocks of *Raninarag-1, Raninagar-2, Beldanga-1, Beldanga-2* and *Raghunathganj-1* were mostly associated with this cluster (Fig. 3.65).

3.6.3.2 Cluster 2:

Cluster 2 is associated with 39 sampling locations. The average *depth* of the groundwater is 44.23 m with low concentration of *arsenic* (0.04 mg/l). The level of *pH* is highest among the clusters with *a* value of 7.43, depicting a slight alkaline condition. The concentration of *TDS* and *EC* was 596.37 mg/l and 1.17 $s/cm^{-1}x\ 10^{-3}$ respectively (Table 3.13). The concentration of *iron* was least among all the clusters (6.06 mg/l). Similar type of condition was also observed in the case of *chloride* and *sulfate* where concentration was least among all the clusters (63.65 mg/l and 167.05 mg/l respectively). The concentration of *total hardness as* $CaCO_3$ was highest among all the cluster (725.92 mg/l). The concentration of *nitrite* was almost like cluster 1 (28.68 mg/l). The blocks which were incorporated in this cluster are *Bharatpur-1, Bharatpur-2, Farakka, Kandi* and *Shamsherganj* mostly located in the western as well as southern fragment of the study area. Some smaller patches were also seen in the central part (Fig. 3.65).

Table: 3.13 Cluster Analysis of Post-monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	No2	Nx
1	46.76	0.08	7.36	593.45	1.18	9.11	88.14	208.24	297.85	27.03	54.00
2	44.23	0.04	7.43	596.37	1.17	6.06	63.65	167.05	725.92	28.68	39.00
3	44.00	0.06	7.35	598.90	1.19	7.01	87.62	834.63	335.35	31.98	40.00
4	47.17	0.03	7.37	620.19	1.23	8.92	94.18	460.33	536.42	32.15	23.00

Nx = total number of samples in the cluster

3.6.3.3 Cluster 3:

This cluster was associated with 40 sampling locations with average *depth* of the groundwater being 44 m. The average concentration of *arsenic* in this cluster was just above the permissible limit (0.06 mg/l). The level of *pH* was least among all the clusters showing alkaline condition (7.35). The level of *TDS* and *EC* showed moderate concentration (598 mg/l and 1.19 s/cm^{-1}x 10^{-3} respectively) (Table 3.13). The concentration of *iron* too was moderate with the value of 7.01 mg/l, that of *chloride* was 87.62 mg/l which was considerably high. The level of sulfate was 834.63 mg/l which was highest among all the clusters, reversely, in *total hardness as* $CaCO_3$ it was low among the clusters (335.35 mg/l). The concentration of *nitrite* was 31.98 mg/l showing higher concentration. The clusters are mostly located in the blocks of *Lalgola, Nabagram, Raghunathganj-2* and *Behramapur.* Spatially, concentrated in the north central portion of Murshidabad District (Fig. 3.65).

3.6.3.4 Cluster 4:

Cluster 4 was associated with 23 sampling locations. The average *depth* of the groundwater was 47.17 m while that of *arsenic* was least among all the clusters (0.03 mg/l). The level of *pH* was indicated slight alkaline condition with a value of 7.37.

TDS and *EC* had highest value among all the clusters 620.19 mg/l and 1.23 s/cm^{-1}x 10^{-3} respectively (Table 3.13).

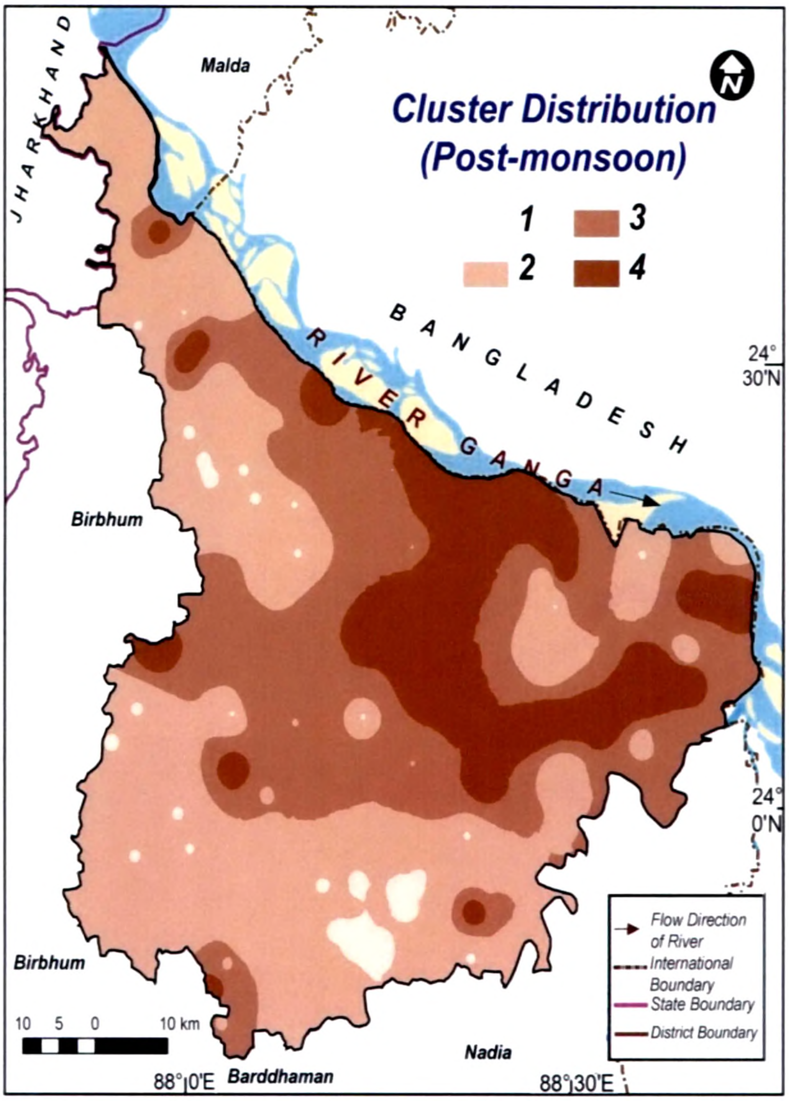


Fig. 3.65: Cluster Distribution during Post-monsoon Season

The *iron* was moderately concentrated (8.92 mg/l) while *chloride* concentration among all the clusters was the highest (94.18 mg/l) (Fig. 3.65). A moderate concentration of *sulfate* was observed in this cluster with a value of 460.33 mg/l. *Total hardness as $CaCO_3$* showed moderate concentration of 536.42 mg/l while concentration of *nitrite* is highest among all the clusters (32.15 mg/l). The blocks of

Jiagunj and *Bhagawangola-1* were largely associated with these clusters concentrated in the peripheral region of the district.

3.7 Seasonal Variability:

Paired t-test was performed on the parameter in different seasons on 156 samples with 95 % significance level. The results obtained from the analysis indicated the pattern of change in the mean of the parameters in different seasons. To perform the analysis, three pairs had been formed (Table 3.14). Results obtained from the analysis are illustrated for each of the parameters-

Table: 3.14 Pairs of Different Seasons for Seasonal Variability

Parameters	Pre-monsoon & Monsoon	Monsoon & Post-monsoon	Pre-monsoon & Post-monsoon
Arsenic	Pair 1a	Pair 2a	Pair 3a
pH	Pair 1p	Pair 2p	Pair 3p
TDS	Pair 1t	Pair 2t	Pair 3t
EC	Pair 1e	Pair 2e	Pair 4e
Iron	Pair 1i	Pair 2i	Pair 3i
Chloride	Pair 1c	Pair 2c	Pair 3c
Sulfate	Pair 1s	Pair 2s	Pair 3s
Total Hardness as $CaCO_3$	Pair 1th	Pair 2th	Pair 3th
Nitrite	Pair 1n	Pair 2n	Pair 3n

The letters written after the pair numbers are the initial letter(s) of the parameters.

3.7.1 Arsenic:

Correlation value of Pair 1a, Pair 2a and Pair 3a seasons are +0.797, +0.634 and +0.881 respectively (Table 3.15). The t-statistic was higher than the tabulated values indicating a significant variation in *arsenic* concentration in Pair 1a and Pair 2a, where as in Pair 3a the t-statistic was lesser than the tabulated one. In case of Pair 1a

Table: 3.15 Correlation and Paired 't' statistics of different seasons.					
Pairs	Seasons Combinations	Correlation	t statistics	df	Sig. (2-tailed)
Pair 1a	pre-monsoon - monsoon	0.797	4.944	155	0.000
Pair 2a	monsoon - post-monsoon	0.634	4.071	155	0.000
Pair 3a	pre-monsoon - post-monsoon	0.881	**0.585**	155	0.560
Pair 1p	pre-monsoon - monsoon	0.216	7.927	155	0.000
Pair 2p	monsoon - post-monsoon	0.316	8.195	155	0.000
Pair 3p	pre-monsoon - Post-monsoon	0.391	**1.679**	155	0.095
Pair 1t	pre-monsoon - monsoon	0.720	13.884	155	0.000
Pair 2t	monsoon - post-monsoon	0.612	**1.753**	155	0.082
Pair 3t	pre-monsoon - post-monsoon	0.452	8.336	155	0.000
Pair 1e	pre-monsoon - monsoon	0.719	13.639	155	0.000
Pair 2e	Monsoon - post-monsoon	0.619	**1.093**	155	0.276
Pair 3e	pre-monsoon - post-monsoon	0.463	8.856	155	0.000
Pair 1i	pre-monsoon - monsoon	0.235	**0.095**	155	0.924
Pair 2i	Monsoon - post-monsoon	0.346	**0.706**	155	0.482
Pair 3i	pre-monsoon - post-monsoon	0.222	**0.474**	155	0.636
Pair 1c	pre-monsoon - monsoon	0.420	3.717	155	0.000
Pair 2c	Monsoon - post-monsoon	0.413	4.214	155	0.000
Pair 3c	pre-monsoon - post-monsoon	0.689	**0.113**	155	0.910
Pair 1s	pre-monsoon - monsoon	0.590	7.912	155	0.000
Pair 2s	Monsoon - post-monsoon	0.410	8.320	155	0.000
Pair 3s	pre-monsoon - post-monsoon	0.853	3.322	155	0.001
Pair 1th	pre-monsoon - monsoon	0.572	3.760	155	0.000
Pair 2th	Monsoon - post-monsoon	0.459	5.352	155	0.000
Pair 3th	Pre-monsoon - post-monsoon	0.859	2.482	155	0.014
Pair 1n	pre-monsoon - monsoon	0.812	5.399	155	0.000
Pair 2n	Monsoon - post-monsoon	0.611	**0.175**	155	0.861
Pair 3n	pre-monsoon - post-monsoon	0.677	4.085	155	0.000

df= degree of freedom, the analysis was done at 95% significance level.
The boldfaced values in the table are lesser than the tabulated t values.

and Pair 2a null hypothesis can be rejected while, in case of Pair 3a null hypothesis can be accepted (Table 3.16). Further, it can be concluded that in pre-monsoon & monsoon and monsoon & post-monsoon, significant change was observed while pre-monsoon and post-monsoon season, no significant change was detected.

3.7.2 pH:

Correlation values of Pair 1p, Pair 2p and Pair 3p were +0.216, +0.316 and +0.391 respectively. In Pair 1p and Pair 2p the t-statistic value was more than the tabulated value (-7.927 and 8.195 respectively) (Table 3.15) indicating a significant change while

Pair 3p showed t-statistic less than the tabulated value (-1.679). It can be inferred from the results that from pre-monsoon & monsoon and monsoon & post-monsoon, Table: 3.16 Seasonal Variability of Parameters

Parameters	Pre-monsoon & Monsoon		Monsoon & Post-monsoon		Pre-monsoon & Post-monsoon	
	Null Hypothesis	Alternative Hypothesis	Null Hypothesis	Alternative Hypothesis	Null Hypothesis	Alternative Hypothesis
Arsenic		√		√	√	
pH		√		√	√	
TDS		√	√			√
EC		√	√			√
Iron	√		√		√	
Chloride		√		√	√	
Sulfate		√		√		√
Total Hardness as $CaCO_3$		√		√		√
Nitrite		√	√			√

significant change was witnessed. Hence, in Pair 1p and Pair 2p, null hypothesis can be rejected while in case of Pair 3p it can be accepted.

3.7.3 TDS:

In *TDS* the correlation values of the pairs were +0.720, +0.612 and +0.452 respectively. The t-statistic for the pairs was +13.884, -1.753 and +8.336 respectively. The t-statistic was greater than the tabulated t value i.e. 1.975, in Pair 1t and Pair 3t while in Pair 2t, the t-statistic was lesser than the tabulated value. The former indicated a change in the *TDS* concentration while no significant change was observed in Pair 2t. Thus, in case of Pair 1t and Pair 3t, null hypothesis can be rejected while in Pair 2t, null hypothesis was accepted (Table 3.15).

3.7.4 EC:

In *EC* the correlation value of three Pairs were +0.719, +0.619 and +0.463 respectively. The t-statistic of Pair 1e and Pair 2e were +13.639 and -1.093 while for Pair 3e it was +8.836. For the Pair 1e and 3e the table value was greater than the t-statistic indicated a significant change but for the last Pair 2e it is lesser than t-value illustrating no significant change. Thus for 1e and 3e, alternative hypothesis can be accepted while for Pair 2e, null hypothesis was accepted.

3.7.5 Iron:

The correlation of pairs for *iron* were +0.235, +0.346 and +0.222 respectively. The t-statistic of the pairs were +0.095, -0.706and -0.474. In all the cases the values were smaller than the table value which indicated that there was no significant change amongst the seasons, thus, null hypothesis can be accepted.

3.7.6 Chloride:

The correlation of the Pairs 1c, 2c and 3c were +0.420, +0.413 and +0.689 respectively. The t-statistics indicated that value of Pair 1c and Pair 2c is greater than the table value (-3.7171 and 4.214) while the value of Pair 3c was lesser than the table value (0.113). Hence significant change was observed in Pair 1c and Pair 2c, while in Pair 3c no significant change was observed. Thus, null hypothesis can be rejected for Pair 1c and Pair 2c while in Pair 3c null hypothesis was accepted (Table 3.15).

3.6.7 Sulfate:

For Pairs 1s, 2s and 3s the correlation was +0.590, +0.410 and +0.853 respectively. The t-statistic for the three pairs was higher than the table value (7.912, 8.320 and 3.322). Hence, significant changes were observed in all the seasons. Consequently, alternative hypothesis was observed between all the seasons.

3.7.8 Total Hardness as $CaCO_3$:

The correlation value of *Total Hardness as* $CaCO_3$ the three pairs was +0.572, +0.459 and +0.859 respectively. The t-static was -3.760, +5.352and +2.482 which was greater than the table, indicated a significant change in concentration in different seasons thus alternative hypothesis was accepted in all the season.

3.7.9 Nitrite:

The correlation for *nitrite* was +0.812, +0.611 and +0.677 respectively. The value of t-statistic of Pair 1n and 3n was more than the table value, while for the Pair 2n it was less. Thus, for the two pairs (Pair 1n and Pair 3n) a significant change in the concentration was observed and the null hypothesis can be rejected while for the Pair 2n no significant change was observed, hence, alternative hypothesis was accepted (Table 3.15).

3.8 Discussion:

3.8.1 Pre-monsoon:

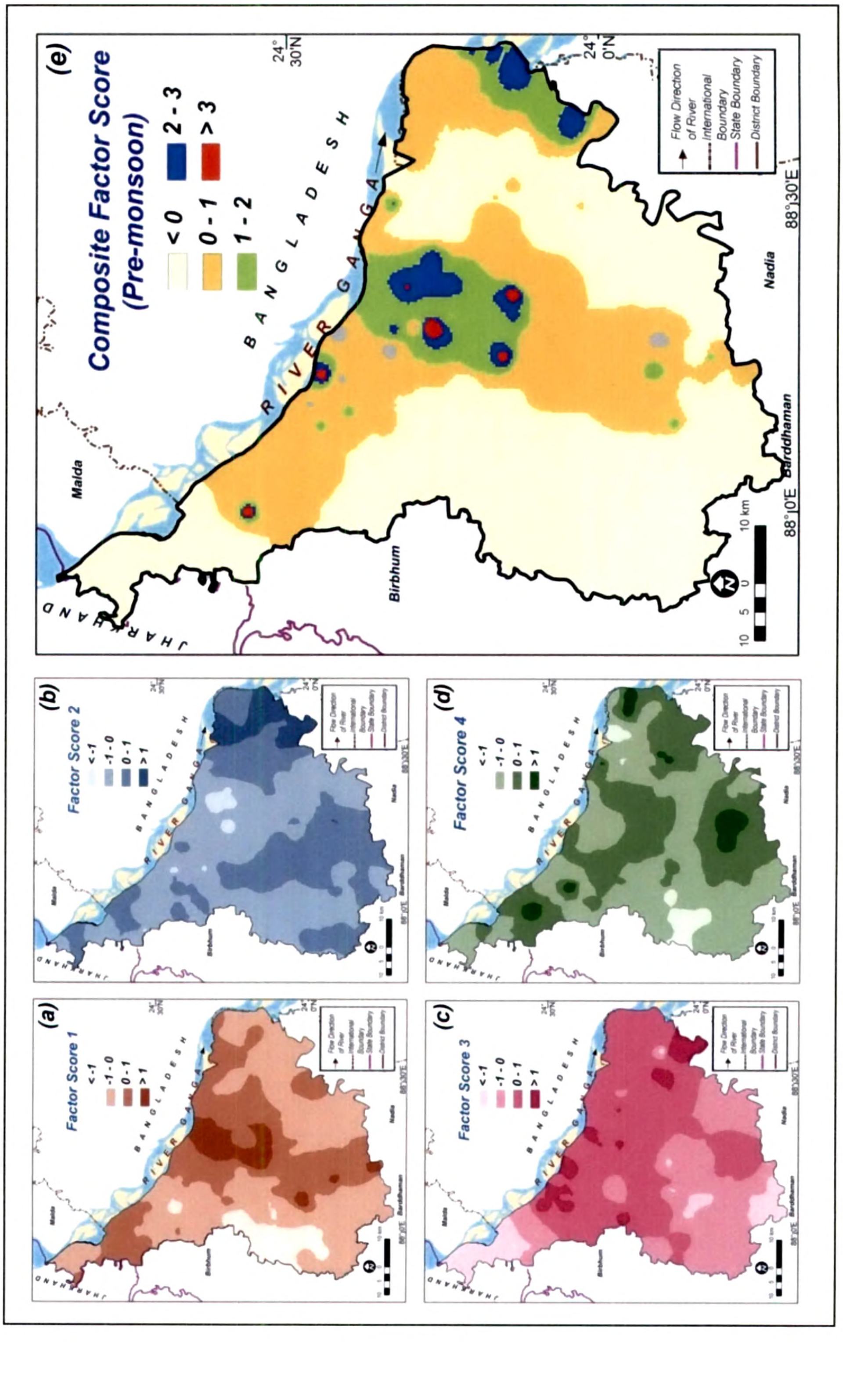


Fig. 3.66: Factor Score Distribution Map during pre-monsoon season

During the pre-monsoon season, factor 1 is associated with the parameters of *TDS*, *EC* and *nitrite*, thus this factor was assigned as 'turbidity factor' (Fig. 3.66a). High turbidity was observed on the northern periphery and also along the narrow trail of the river Bhagirathi. Percolation of river water and mixing with the subsurface groundwater might be one of the governing factors that affects the turbidity (**Ghosh** & **Kanchan**, 2014). This factor decreased gradually on the western as well as on the eastern ends where the number of tributaries and distributaries are less. As per the result, it can be said that these three factors during pre-monsoon season contributed significantly in controlling the overall variability of the groundwater characteristics.

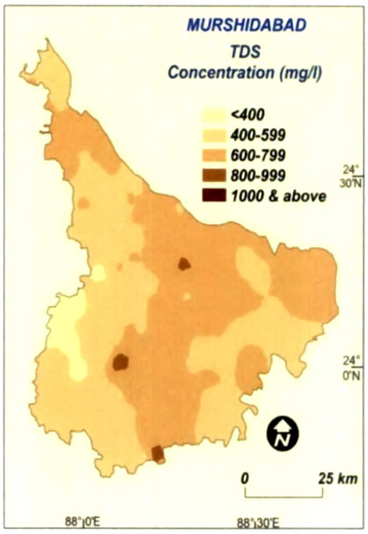


Fig. 3.67: Spatial Distribution of TDS during pre-monsoon season.

Higher average concentration of *TDS*, *EC* and *nitrite* were associated with cluster 1 (Fig. 3.63). This cluster was largely confined in the eastern and north-central part of *Murshidabad* district.

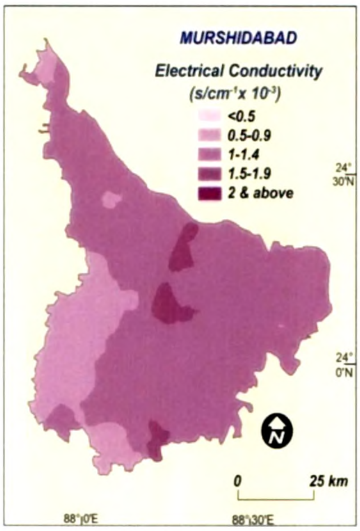


Fig. 3.68: Spatial Distribution of EC during pre-monsoon season.

In cluster 1, the average concentration of *arsenic* was considerably higher (0.08mg/l) and was largely confined in the eastern part. Higher concentration of *TDS* (Fig. 3.67) and *EC* (Fig. 3.68) was located in the central portion and eastern side of the river *Bhagirathi* while *nitrite* concentration (Fig. 3.69) was mostly located in the north central portion of the district.

Factor 2 was associated with *arsenic* and *depth*. Positive loading on the *depth* and negative loading on *arsenic* indicated concentration of *arsenic* in the shallower *depth*.

The easternmost side of the study area depicted very high concentration of *arsenic* at the shallower *depth* (Fig. 3.66b). The aquifer system in the eastern part of river *Bhagirathi* is thick unconfined and is associated with easy interaction and percolation of surface and subsurface water.

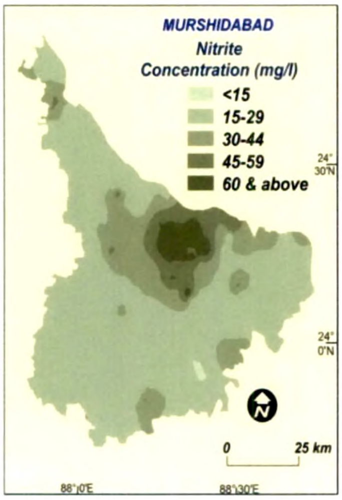


Fig. 3.69: Spatial Distribution of Nitrite during pre-monsoon season.

The results obtained from the cluster analysis showed that, cluster 3 is associated with similar kind of characteristics and were mostly situated in the eastern most segment in a confined area having lesser *depth*. In this season, the *arsenic* concentration was 0.06 mg/l which is just above the permissible limit of BIS (Fig. 3.70). The concentration of *arsenic* in eastern most part of the study area of river Bhagirathi during pre-monsoon season was a common characteristic of cluster 1 and 3.

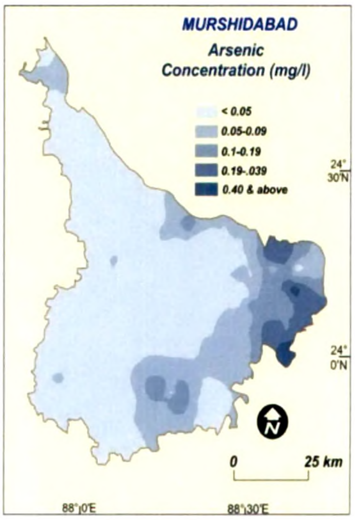


Fig. 3.70: Spatial Distribution of Arsenic during premonsoon season

The results obtained from the inter-factorial relation between factor 1 and 2 depicted that all the parameters had positive characteristics except *arsenic* which illustrated the fact that its concentration was higher at the shallower *depth*. With increasing *depth* concentration lowers down. In case of *TDS*, *EC* and *nitrite* and it was spread throughout the district.

Factor 3 associated with the parameters of *sulfate* and *total hardness as* $CaCO_3$ showed the concentration of *sulfate* (Fig. 3.71) in the eastern side of the river *Bhagirathi*. No definite pattern was observed for *total hardness as* $CaCO_3$ (Fig. 3.72). This phenomenon might be due to the weathering of calcium bearing rocks in the region and excessive use of lime in the agricultural land and subsequently, mixing with the groundwater (**Sawyer** and **McCarthy** 1967,

Giridharan et al. 2008). Considerably higher factor scores were observed in central and north central segment while they were lower in the south western segment (Fig. 3. 66c). Results obtained from the cluster analysis showed that, cluster 3 (Fig. 3.63) was associated with considerably higher average of *sulfate* and *total hardness as* $CaCO_3$ while the highest concentration of later was in cluster 2.

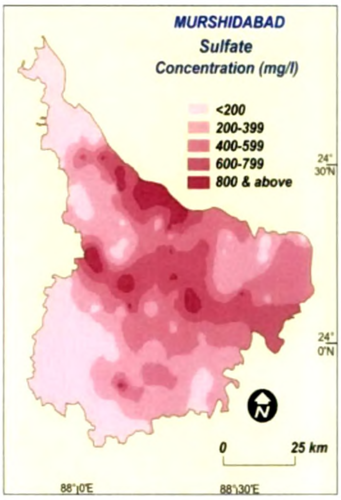


Fig. 3.71: Spatial Distribution of Sulfate during pre-monsoon season.

Inter factorial relation between factors 1 and 3 depicted that the region where *total hardness as* $CaCO_3$ was moderate to lower, the concentration of *TDS* and *EC* and *nitrite* was moderate. Under the same circumstances the concentration of *arsenic* was higher shallower *depth*. Relation between factor 2 and factor 3 had a positive association in all the parameters except *arsenic* and *total hardness as* $CaCO_3$. The factor 3 and cluster 2 both were mostly found in central part of *Murshidabad* district.

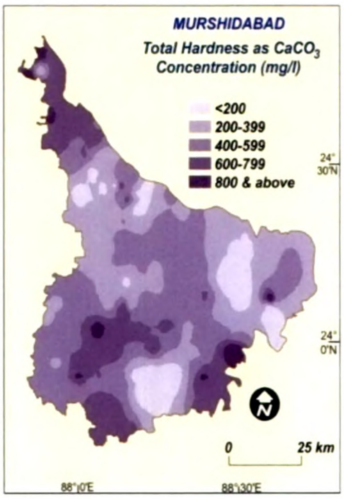


Fig. 3.72: Spatial Distribution of Total Hardness as $CaCO_3$ **during pre-monsoon season.**

pH, *chloride* and *iron* were associated with factor 4 (Fig.3.66d). *pH* is considered to be one of the important parameters which helps in determining the hydro chemical characteristics of groundwater, as the level of *pH* is associated with further chemical reactions (**Ghosh**[1] & **Kanchan** 2014).

The level of *pH* in the central part was slightly alkaline while in the other parts of the district it ranged from normal to slightly acidic (Fig. 3.73). The concentration of *chloride* in the entire region was considerably high except in the western side (Fig. 3.74) while *iron* was much higher in the western and north western segment.

The particular condition can be observed in cluster 1 of *chloride* where the concentration of the *iron*, *chloride* and *pH* was high. The inter factorial relationship among the factor 1 and factor 4, factor 2 and factor 4 and factor 3 and factor 4.

The composite factor score showed major concentration in the north central and eastern part of the district (Fig.3.66e).

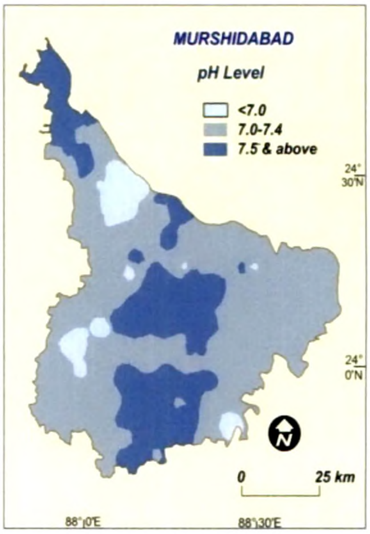


Fig. 3.73: Spatial Distribution of pH during pre-monsoon season.

Thus, in the pre-monsoon season higher concentration of *arsenic* with slightly alkaline condition was noted. Similarity in-terms of the spatial distribution of *arsenic* and *iron* can be observed in the eastern end of the *Murshidabad* district indicating a definite relation between the two. The concentration of *nitrite*, *TDS* and *EC* was related with river as their concentration is much higher nearer to it. This also indicated the interaction of surface and subsurface water (**Oinam** et al. 2011). *Sulfate*, *chloride* and *total hardness as* $CaCO_3$ was extensively found throughout the study area. The results obtained from the factor analysis depicted that factor scores were much higher in the eastern side of the river *Bhagirathi*.

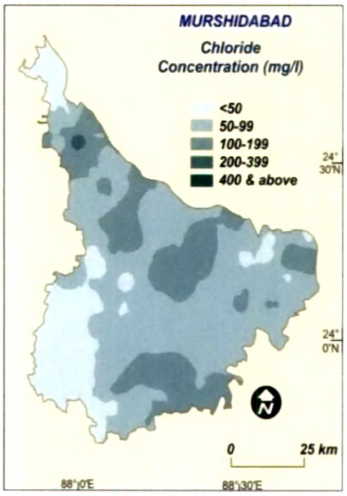


Fig. 3.74: Spatial Distribution of Chloride during pre-monsoon season.

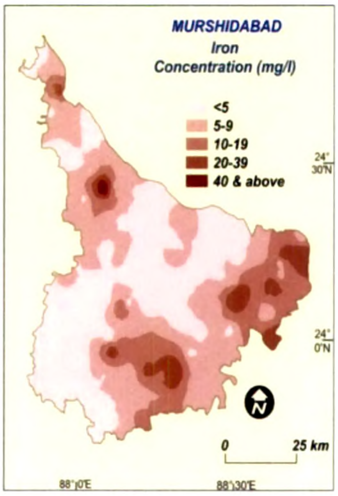


Fig. 3.75: Spatial Distribution of Iron during pre-monsoon season.

3.8.2 Monsoon:

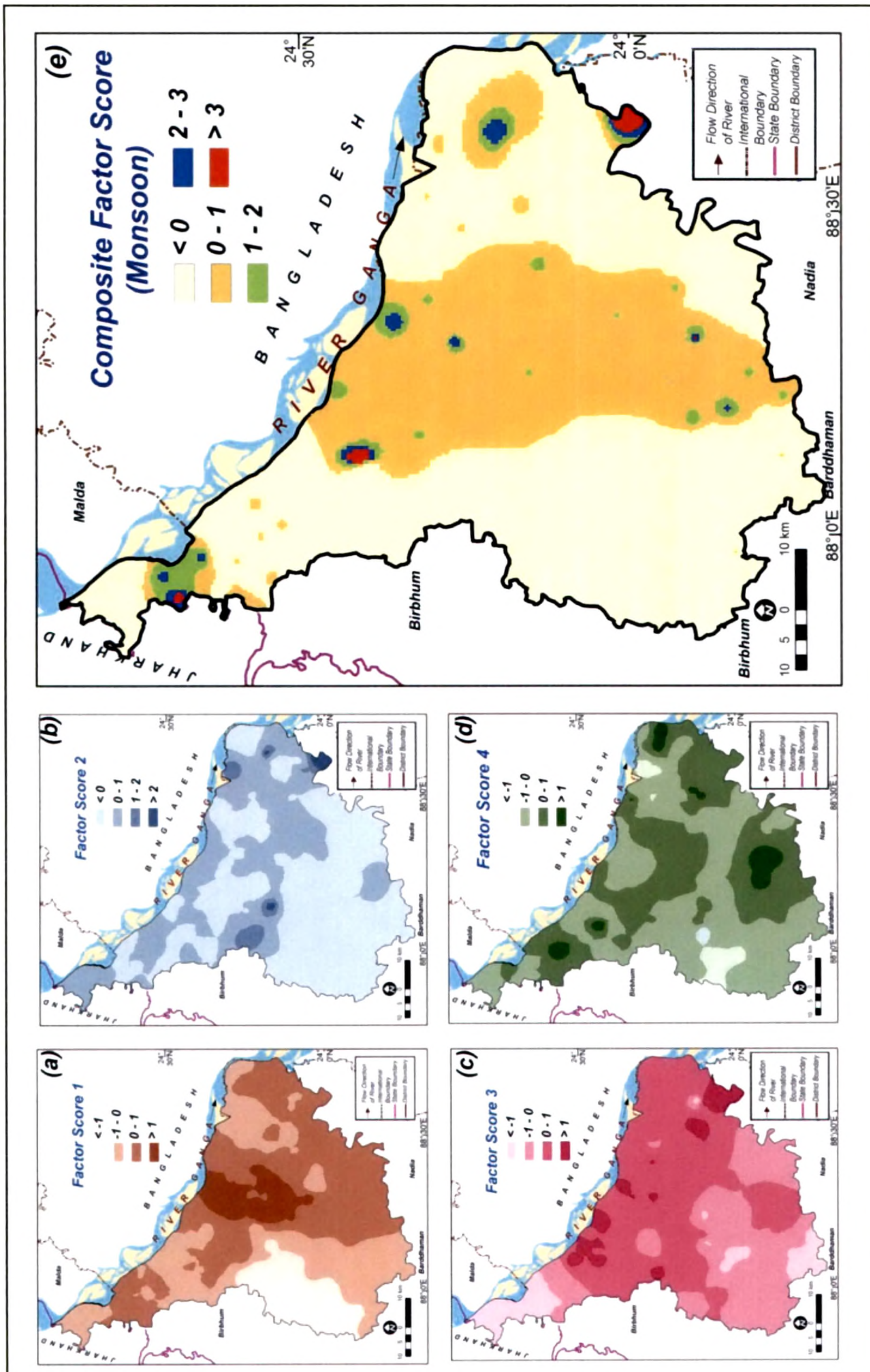


Fig. 3.76: Factor Score Distribution Map during Monsoon Season

During monsoon season, factor 1 is associated with the parameters of *TDS* and *EC* (Fig. 3.76a). In respect to pre-monsoon season, a slight decrease was observed in concentration. In respect to pre-monsoon season, a slight decrease in the concentration of *TDS* and *EC* was observed in the monsoon season. Dilution of subsurface water due to percolation of rain water might be one of the reason behind this condition (Ghosh & Kanchan 2011). The eastern part of the river *Bhagirathi* had a higher level of *TDS* (Fig. 3.77).

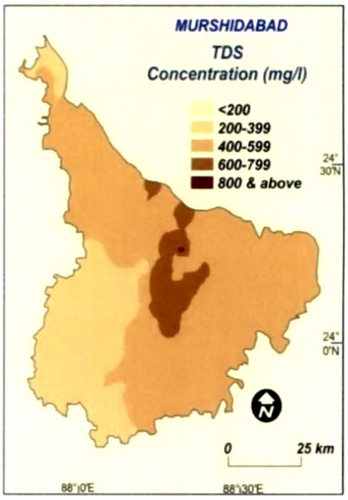


Fig. 3.77: Spatial Distribution of TDS during Monsoon Season.

A narrow trail of higher level of *TDS* and *EC* (Fig. 3.78) can be observed in the central portion of the district which follows the path of the river *Bhagirathi*. The factor score map also confirmed that the entire study area is associated with higher factor score except in its western part (Fig. 3.76a).

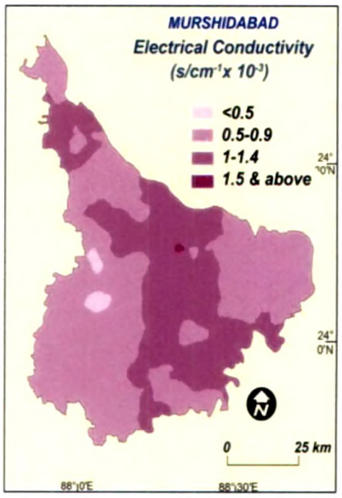


Fig. 3.78: Spatial Distribution of EC during Monsoon Season.

The results obtained from the cluster analysis depicted that cluster 1 was associated with the highest concentration of *TDS* and *EC*. This cluster largely covers the eastern and north western part of the district. On the other hand, this cluster was almost absent in the western most segment indicating a relatively lesser concentration of each of the parameters. Least number of locations was found in this cluster but they are distributed in a much wider area indicating a widespread impact of natural phenomenon. Another fact, which might also contribute in the lowering of the concentration of *TDS* and *EC* in this season is the condition of the aquifers.

Thick unconfined aquifer is found in the eastern part which is associated with easier interaction of surface and subsurface water and there is no significant intervening layer. This leads to easier and faster percolation of water in the eastern part rather than the western segment which has thick semi confined aquifer having intervening layers that slower down the process of percolation (Groundwater Information Booklet, 2007). *Chloride*, *sulfate*, *total hardness as $CaCO_3$*, and *depth* form the second factor (Fig. 3.76b). The concentration of *chloride* was mostly confined in the central and eastern part of the district (Fig. 3.79). *Total hardness as $CaCO_3$* showed extensive distribution and is mostly confined in the central region (Fig. 3.80). The level of *sulfate* was also high in the entire district. *Total hardness as $CaCO_3$* and *chloride* concentration increased in this season, but the level of *sulfate* decreased slightly. Greater runoff from the agricultural fields, percolation through the soil and mixing with the groundwater might govern this condition.

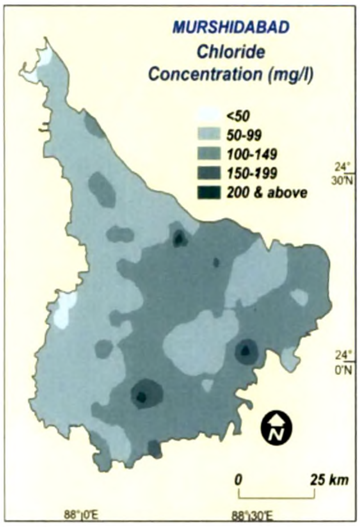


Fig. 3.79: Spatial Distribution of Chloride during Monsoon Season

The factor score are considerably higher in northern peripheral part and lower in central part. Cluster analysis depicts highest concentration of *chloride* and *sulfate* in

cluster 3 which was confined in the central part (Fig. 3.81). In the same cluster, the concentration of *arsenic* was also very high. Both the results (factor and cluster analysis), demarcated the eastern portion as the most contaminated in respect to factor 2. The inter-factorial relationship between factor 1 and 2 explained a negative relationship of *chloride* with all other parameters. Factor 3 is related with *arsenic* and *iron* and its concentration was found higher in the eastern part. No significant change in *iron* concentration was observed between pre-monsoon and monsoon season, indicating predominance of this element

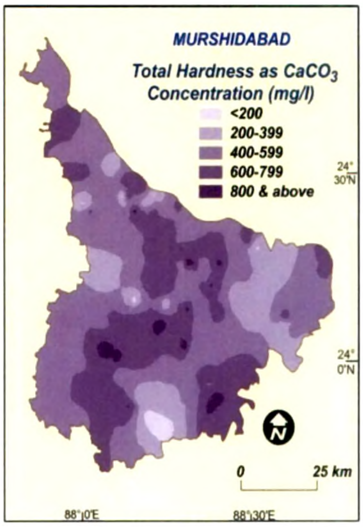


Fig. 3.80: Spatial Distribution of Total Hardness as $CaCO_3$ during Monsoon Season.

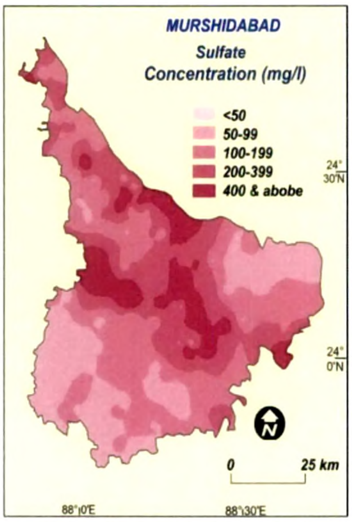


Fig. 3.81: Spatial Distribution of Sulfate during Monsoon Season

in shallower aquifers (Fig. 3.82). Entire region, except western part of the river *Bhagirathi* depicted higher factor score (Fig. 3.76c).

As per cluster analysis, cluster 2 had 59 sampling location and the highest average *iron* concentration was confined in the eastern and western part of river *Bhagirathi* (Fig. 3.64). The average concentration of *arsenic* decreased to a considerable level and was confined in a small patch in the eastern side (Fig. 3.83). This decrease might be due to the dilution of rain water (**Ghosh** & **Kanchan** 2011). Even in this season the eastern side showed very high concentration of arsenic.

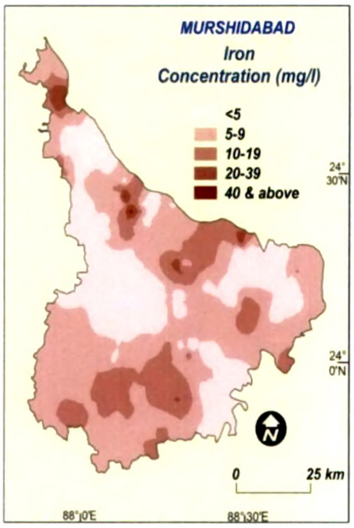


Fig. 3.82: Spatial Distribution of Iron during Monsoon Season

The inter factorial relation between factor 1 and 3 depicted a positive relationship with each other indicating no single factor being dominating and controlling. Inter factorial relation between factor 2 and 3, on the other hand, showed a negative relationship with *total hardness as* $CaCO_3$, *chloride* while positive association of *sulfate* and *depth* with other parameters like *iron* and *arsenic*. Thus, regions with higher *arsenic* and *iron* concentration have lower *total hardness as* $CaCO_3$. On the other hand, cluster 4 depicts least average arsenic concentration but at the same time the *total hardness as* $CaCO_3$ was highest (Fig. 3.76d) (Table. 3.12).

pH and *nitrite* were included in the fourth factor with least variability of the entire data set. In this case, *pH* is associated with positive loading while the *nitrite* is associated with negative loadings (Table. 3.7). *pH* value was slightly higher in the entire district (Fig. 3.84). On the other hand, *nitrite* is concentrated in a very small patch in the north central portion (Fig. 3.85). Other than this, there is no significant concentration of this element which indicates excessive use of nitrogen bearing pesticides and fertilizers in the agricultural ground (**Schmoll** et al. 2006, **Mishima** et al. 2010). The factor scores are considerably higher (Table. 3.7) (Fig. 3.76d). The cluster analysis depicted two clusters viz. cluster 1 and 4 where the condition of these two parameters are almost identical (Fig. 3.64) (Table. 3.12). These clusters are mostly confined in the eastern side of the river *Bhagirathi* which also coincide with the region of higher factor scores (Fig. 3.64). The inter factorial relationship between factor 1 and 4, factor 2 and 4 and factor 3 and 4 depicted the facts that during this season the parameters of *nitrite*, *chloride* and *total hardness as* $CaCO_3$ had a negative relationship with other parameters like *arsenic*, *sulfate*, *TDS*, *EC* and *pH*. The composite factor score (Fig. 3.76e) depicted the overall characteristics of the factors during monsoon season that showed major concentration along the river *Bhagirathi* in different patches.

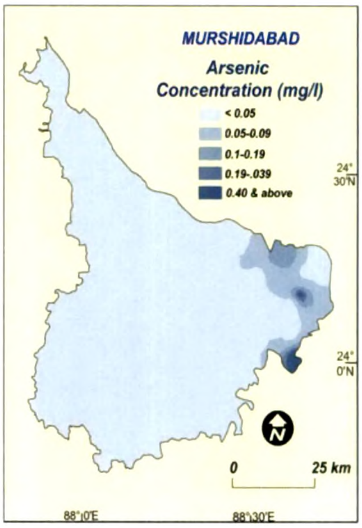


Fig. 3.83: Spatial Distribution of Arsenic during Monsoon Season

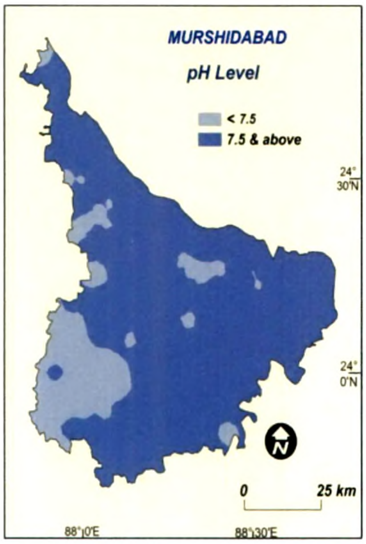


Fig. 3.84: Spatial Distribution of pH during Monsoon Season

Thus between pre-monsoon and monsoon season significant change in concentration was observed in all the parameters except *iron*. Rainfall is one of the important factors that helped in deterring the characteristics of groundwater and changing its nature (**Ghosh**[1] & **Kanchan** 2011). During pre-monsoon all the factors aligned in a particular way but during monsoon season their orientation is relatively less oriented (Fig. 3.60 and Fig. 3.62) that showed significant shift of the factor scores.

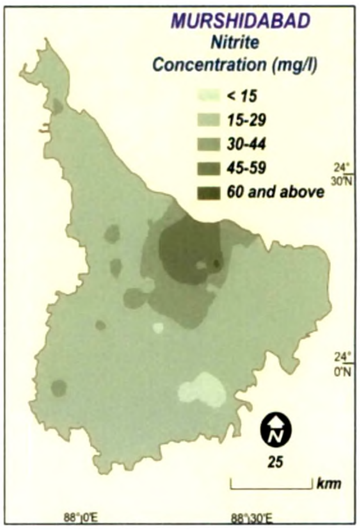


Fig. 3.85: Spatial Distribution of Nitrite during Monsoon Season

3.8.3 Post-monsoon:

During post-monsoon factor 1 is associated with the parameters of *TDS and EC*. This condition can be explained with the fluctuation in the level of groundwater. As the level of groundwater or the volume of water decreases the concentration respectively. The location of higher concentration of *TDS* and *EC* were located nearer to the rivers. The concentration of *TDS* was much higher along the path of the river *Bhagirathi* (Fig. 3.86 and Fig. 3.87).

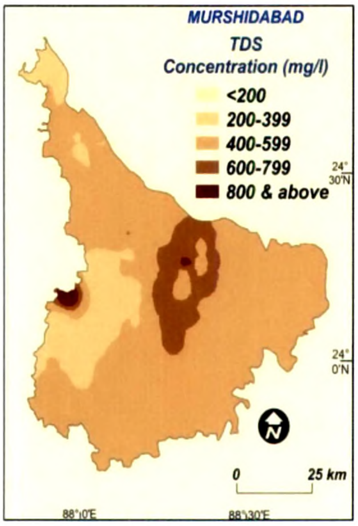


Fig. 3.86: Spatial Distribution of TDS during Post-monsoon Season

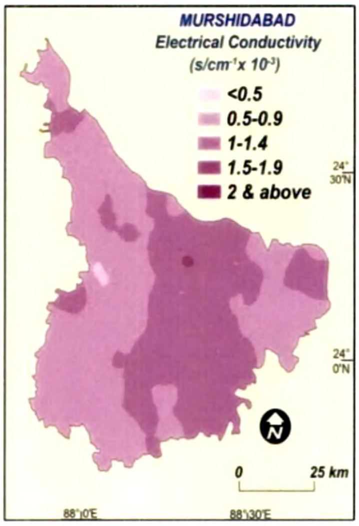


Fig. 3.87: Spatial Distribution of EC during Post-monsoon Season.

Factor 1 depicted that, the central and eastern part of the river *Bhagirathi* is associated with higher factor scores (Fig.3.88a) while in the western segment factor scores are relatively lesser indicating lesser concentration of parameters except a small patch which might be due to some local phenomenon. Factor 2 score were associated with *total hardness as $CaCO_3$*,

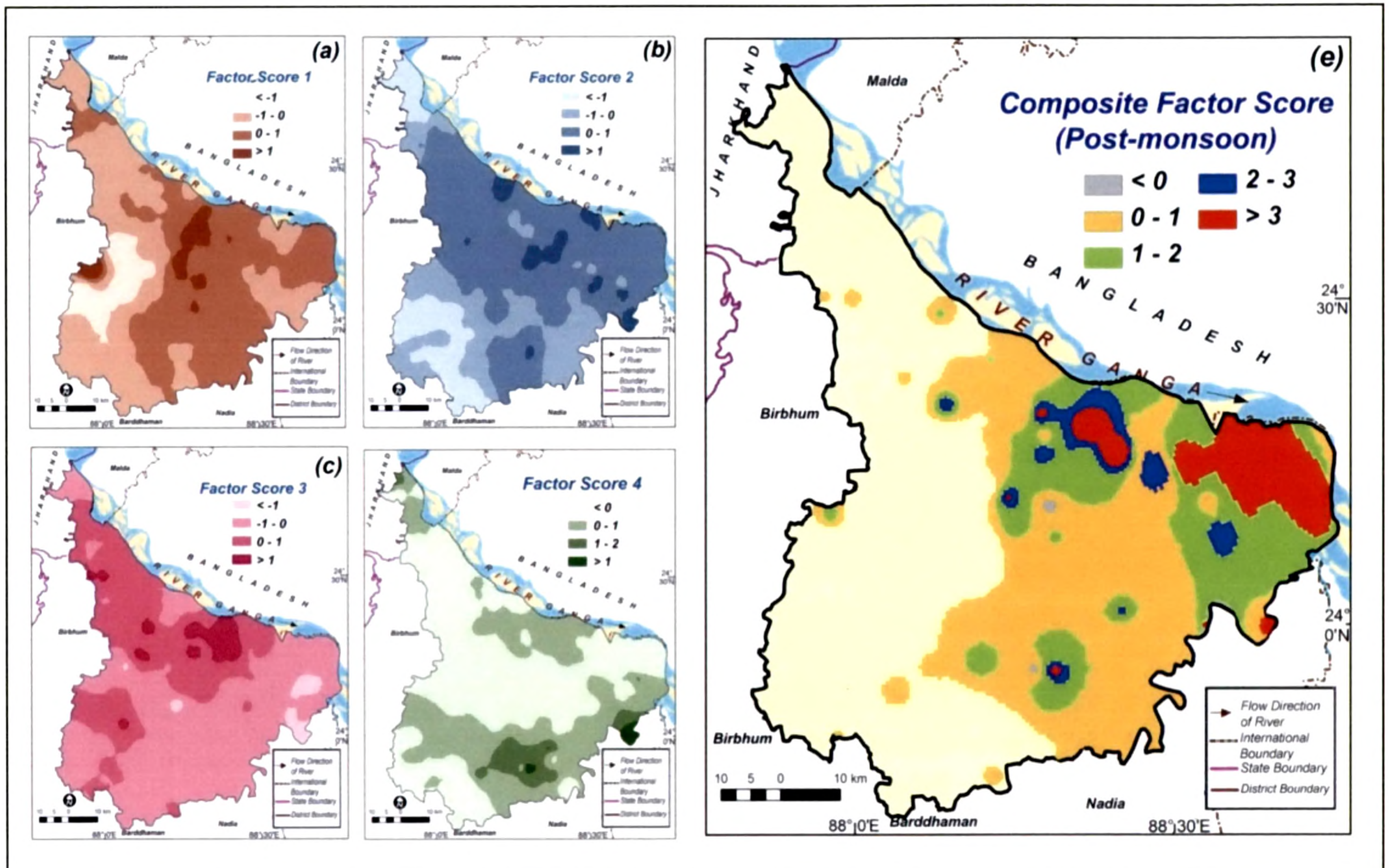


Fig. 3.88: Factor Score Distribution Map during Post-monsoon Season

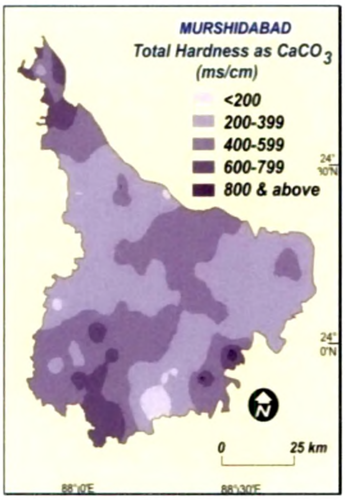


Fig. 3.89: Spatial Distribution of Total Hardness as $CaCO_3$ during post-monsoon season.

chloride and *sulfate*. The factor scores were associated with higher values in the entire region except western part (Fig. 3.88b). The concentration of *total hardness as* $CaCO_3$ was extensively distributed throughout the space and maximum concentration was in the south western and central part which confronted with the rivers (Fig. 3.89). The results obtained from the cluster analysis depicted highest average concentration of *total hardness as* $CaCO_3$ in the second cluster (Table. 3.13). The use of *chloride* based fertilizers in the agricultural field might be one of the major reason behind it (Hudak 1999). Cluster analysis results indicated that cluster 4 is associated with highest *chloride* and *nitrite* concentration.

The particular cluster is located in the entire district except western side of the river *Bhagirathi* (Fig. 3.65). Spatial distribution of *chloride* showed almost even distribution throughout the space with smaller patches in the northern and southern part. The south western part is associated with the least concentration (Fig. 3.90). Both the result from factor distribution map and cluster distribution map are coinciding with each other (Fig. 3.88b). This effect is also observed in the concentration of *sulfate*. As the rainwater percolates it dissolves the minerals of sulfur and mixed up with the groundwater, hence, an increase in the concentration of *sulfate* can be observed in the post monsoon season (O'Day et al. 2004). The entire district showed considerably higher

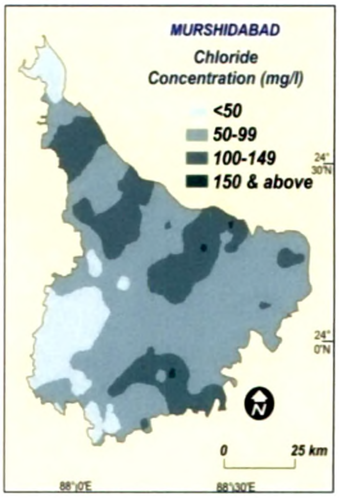


Fig. 3.90: Spatial Distribution of Chloride during post-monsoon season.

concentration of sulfate while central portion was associated with highest concentration (Fig. 3.91).

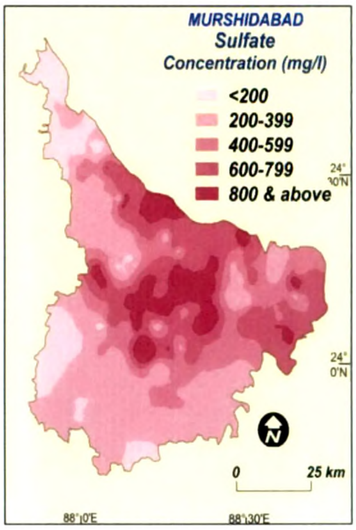


Fig. 3.91: Spatial Distribution of Sulfate during post-monsoon season.

Factor 3 associated with the parameters of *pH* and *nitrite* and the entire district is associated with slightly acidic condition (Fig.3.88c). Patches of acidic condition was observed in southern and eastern portion value ranging between less than 7 to 7.5. The factor scores were higher in the north central and western part and it decreases in the central part of the district. The values of *pH* indicated slightly acidic condition in the southern portion (Fig. 3.92) while concentration of *nitrite* is considerably lower in the north central region (Fig. 3.93).

As the samples belonged to post-monsoon season, the rainwater played an important role in altering the condition of groundwater. As the rainwater itself is slightly acidic in nature and it might help in lowering down the level of *pH* (Rodriguez et al. 2004). The inter factorial relationship between factor 2 and 3 showed a positive relation with all the parameters other than *total hardness as* $CaCO_3$. During post-monsoon, the level of *pH* turns slightly acidic while the concentration of *arsenic* increases.

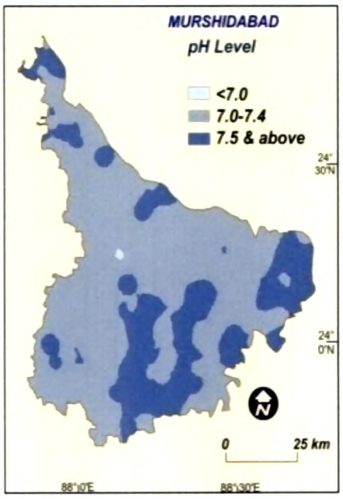


Fig. 3.92: Spatial Distribution of pH during post-monsoon season.

Nitrite, on the other hand, was concentrated in the north central segment where river Bhagirathi distributed from river *Ganga* (Fig. 3.93). The concentration of *nitrite* in a particular region indicates the probable association of anthropogenic sources as they are stable throughout the time period (Canter 1996).

Factor 4 was associated with the parameters of *arsenic, iron* and *depth* (Fig. 3.88d)

The concentration of *arsenic* was higher towards the east while in the west of the district the concentration was considerably lower (Fig. 3.94) at the same time *iron* concentration is extensively found throughout the space. During this season the mean concentration was highest (Fig. 3.95). It revealed that the oxidation had taken place and helped in oxidizing the *iron* present in the subsurface (**Akai** et al. 2004).

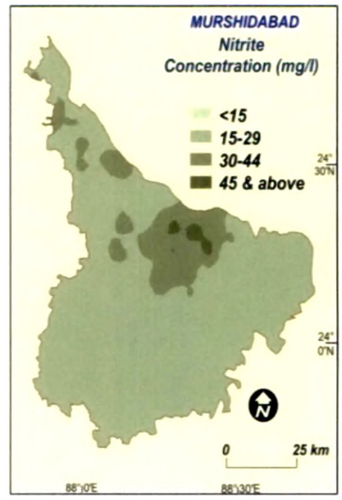


Fig. 3.93: Spatial Distribution of Nitrite during post-monsoon season

The inter-factorial relationship between the factor 1 and 4 showed a positive relationship between *chloride* and *nitrite* with *iron* and *depth* while a negative relation exists with *TDS*. The relation between factor 3 and 4 was positive between all parameters except *TDS*.

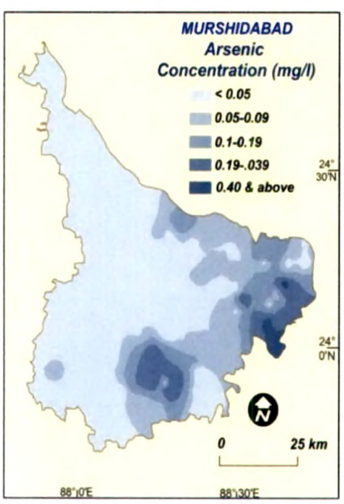


Fig. 3.94: Spatial Distribution of Arsenic during post-monsoon season.

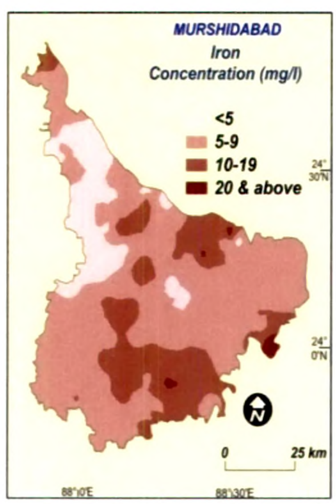


Fig. 3.95: Spatial Distribution of Iron during post-monsoon season

The relation between factor 2 and 4 showed that the concentration of *arsenic* with *iron* and *depth*. The higher concentration of *arsenic* and *iron* was found in the shallower aquifers. At the same time the negative sign of *TDS* and *total hardness as* $CaCO_3$ indicated increasing *depth*, *arsenic* and *iron* concentration these are generally decreases.

The concentration of *arsenic* from pre-monsoon to monsoon season showed significant change according to the result of paired 't' test.

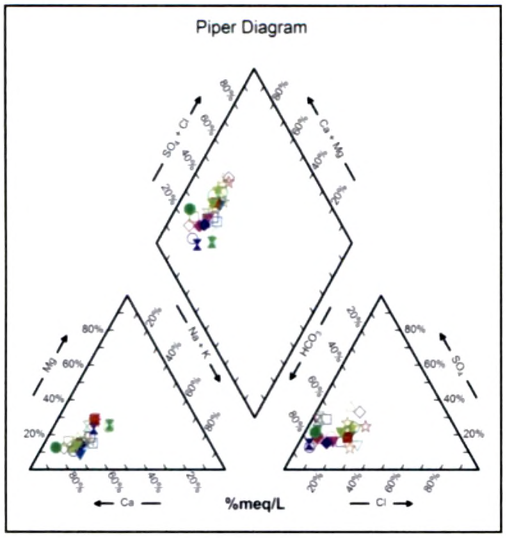


Fig. 3.96: Distribution of Major Ions during pre- monsoon season

The influence of rainfall might be one of major reason behind it which helped in lowering down relative concentration of *arsenic* (**Ghosh** & **Kanchan** 2011). On the other hand, concentration manifold increases was observed in post-monsoon in the eastern part of the district indicating that as the level of groundwater decreases due to evaporation and groundwater withdrawal for drinking, irrigation and other purposes (**Harvey** et al. 2002).

The level of *pH* also showed a considerable change from pre-monsoon to monsoon and monsoon to post-monsoon while no considerable change was observed between

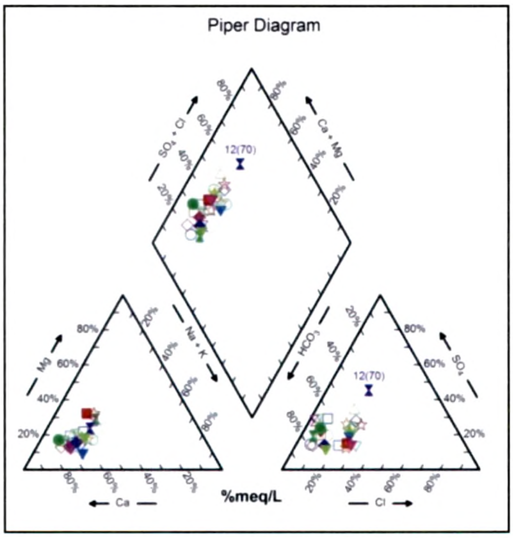


Fig. 3.97: Distribution of Major Ions during monsoon Season

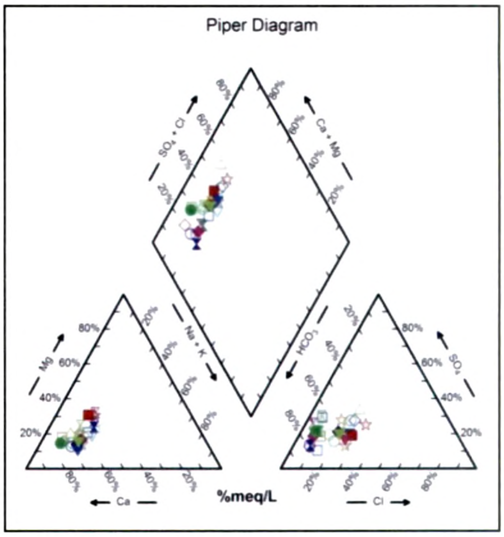


Fig. 3.98: Distribution of Major Ions during post-monsoon season

pre-monsoon to post-monsoon seasons. The distribution of major ions in three seasons do not showed any significant change (Fig 3.96, Fig. 3.97 and Fig 3.98) that indicated relatively stable characteristics of major ionic distribution. In all the seasons the groundwater samples were clustered around the particular segment of the graphs. The level of *pH* in post-monsoon was slightly acidic. The concentration of *TDS* and *EC* depicted a similar pattern. During the monsoon season there is considerable decrease while during post-monsoon, an increase in the concentration was observed indicating the importance of rainfall. The concentration of both the elements was higher in the regions nearer and along the rivers. The concentration of *iron* does not showed any significant change in concentration throughout the year which indicated that there is predominance of *iron* in the groundwater as well as aquifers. The correlation matrix of different seasons did not reflect any significant association which indicated the importance of each parameter as individual (Table. 3.17, Table. 3.18 and Table. 3.19) which also showed the importance of associational analysis rather one to one. Factor scores and cluster analysis also indicate a relatively stable zone of higher concentrations.

The concentration of *arsenic* and *iron* was also high in the shallower aquifer. During pre-monsoon and post-monsoon the concentration was relatively higher where as during monsoon season it decreased. The parameters like *chloride* and *total hardness as* $CaCO_3$ also depicted similar pattern. One of the reasons might be the dilution of *chloride* bearing minerals with rainwater and mixing up with the groundwater. Other than this, the excessive use of *chloride* based fertilizers is another important factor. During the monsoon season the excess amount of fertilizers are diluted with water, percolated and come in contact with the groundwater which can increases its concentration. Soil sampling locations are depicted in the figure 3.98. 12 soil samples from each of the blocks were collected. Sand, silt and clay percentage for each of the blocks were calculated. The results of 12 soil samples were averaged in one for each of the block thus 26 soil sample result was obtain for 26 blocks . The grain size distribution in the entire district also depicted silty-clay type of soil with relatively less availability of sand (Fig. 3.100). It was observed that to improve the productivity of the soil, lime is sprinkled in the agricultural fields during the monsoon and this phenomenon is also responsible for the increases

Table: 3.17 Correlation Matrix (pre-monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-0.175	1.000								
pH	-0.050	0.049	1.000							
TDS	-0.011	0.053	0.164	1.000						
EC	-0.010	0.054	0.162	1.000	1.000					
Iron	-0.121	0.214	-0.008	-0.062	-0.061	1.000				
Chloride	-0.033	-0.030	0.111	0.199	0.198	0.206	1.000			
Sulfate	0.025	0.110	0.034	0.112	0.113	0.070	0.174	1.000		
Total Hardness	0.139	-0.259	0.054	-0.050	-0.050	-0.166	-0.128	-0.283	1.000	
No_2	0.088	-0.029	0.005	0.310	0.310	-0.120	0.159	0.104	0.014	1.0

Table: 3.18 Correlation Matrix (monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-0.176	1.000								
pH	-0.109	0.051	1.000							
TDS	-0.003	0.080	0.150	1.000						
EC	-0.004	0.083	0.154	0.999	1.000					
Iron	0.422	-0.036	-0.083	-0.071	-0.071	1.000				
Chloride	-0.007	-0.066	0.106	0.239	0.247	0.036	1.000			
Sulfate	0.010	0.157	-0.023	0.112	0.110	0.087	-0.206	1.000		
Total Hardness	0.208	-0.213	-0.053	0.093	0.096	0.078	0.175	-0.302	1.000	
NO_2	0.153	0.031	-0.138	0.191	0.193	0.162	0.117	0.220	0.025	1.000

Table: 3.19 Correlation Matrix (post-monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-.087	1.000								
pH	-.075	.078	1.000							
TDS	.024	-.009	.001	1.000						
EC	.018	-.011	.012	.995	1.000					
Iron	.106	.242	.067	.070	.074	1.000				
Chloride	-.022	.031	-.003	.190	.187	.112	1.000			
Sulfate	-.031	.044	.140	.104	.104	.115	.194	1.000		
Total Hardness	.070	-.232	-.083	.076	.081	-.043	-.166	-.211	1.000	
NO_2	.084	-.046	-.239	.263	.255	.045	.259	.100	.061	1.00

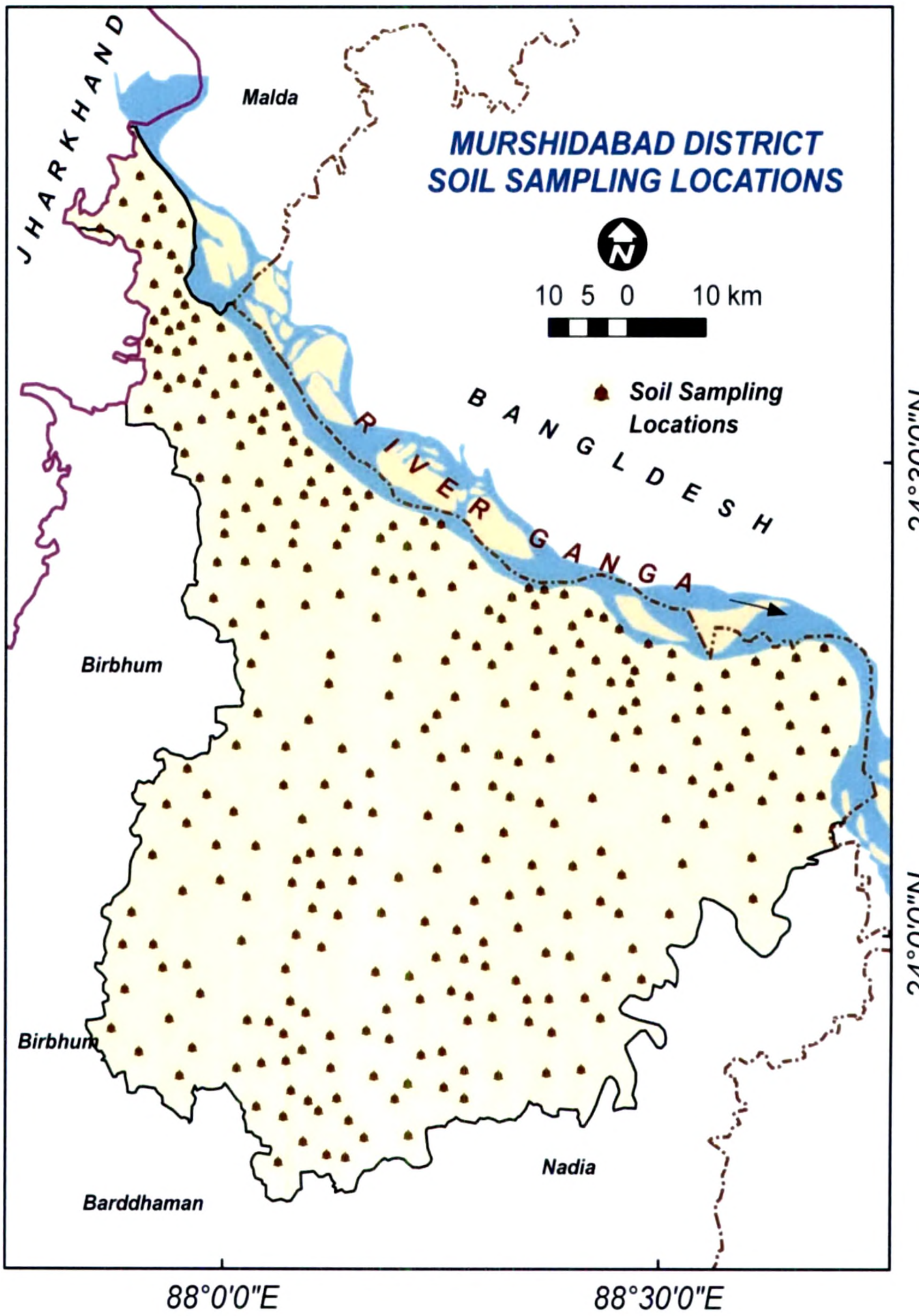


Fig. 3.99: Soil Sampling Locations

in *total hardness as* $CaCO_3$.The concentrations of *total hardness as CaCO3* and *sulfate* were higher during. The dissolution from the minerals such as gypsum and anhydrate were the major sources of *sulfate* in groundwater (Hudak 1999). The concentration of *nitrite* in groundwater was found in the north central part of the district.

The major sources of *nitrite* in groundwater are organic nitrates including anthropogenic local pollution and livestock manure (Kumazawa 2002, Gupta et al. 2008). The concentration of *nitrite* decreases during monsoon but remains stable in the post-monsoon indicating the importance of rainfall in diluting the element. The zones of higher and lower concentration is relatively stable throughout the time period. So concludingly, spatial distribution of different parameters does not showed any significant change.

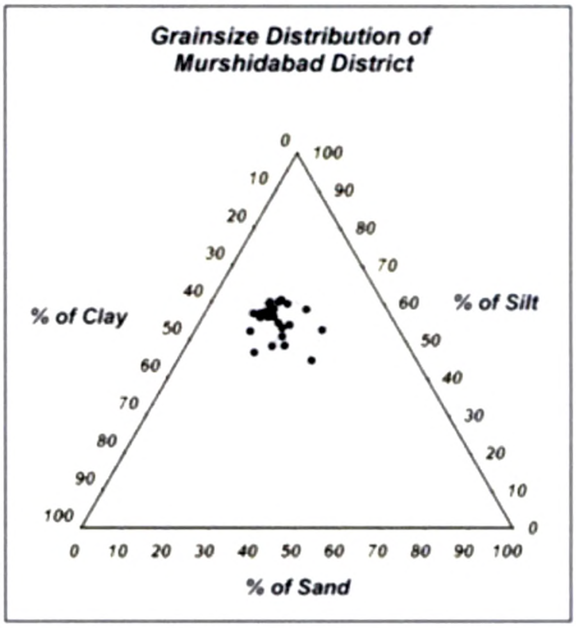


Fig. 3. 100: Grain Size Characteristics

Resume: In this chapter, the geochemical characteristics of groundwater was anlysed with ten parameters. Most of the parameters including arsenic, had higher concentration in eastern segment of the study area. Geochemical parameters showed significant association with different season. Multivariate statistical analysis helped in understanding the relationship among the parameters. The following chapter analyses the association between the arsenic in groundwater and its effects on human health.